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AND

Journal of The Mineralogical Society.

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ASSISTED BY A COMMITTEE OF COUNCIL.

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THE MINERALOGICAL SOCIETY

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, June 16, 1908.

Professor H. A. Miers, D.Sc., F.R.S., President, in the Chair.

The resignation of the Earl of Berkeley was announced.

Resolved to nominate Dr. A. E. H. Tutton as Vice-President in place of Professor G. D. Liveing; and Messrs. W. Barrow, F. N. A. Fleischmann, H. Hilton, and A. Hutchinson, in place of the four retiring Ordinary Members of Council (Messrs. J. P. De Castro, J. S. Flett, F. W. Rudler, and A. E. H. Tutton).

Dr. G. T. Prior was appointed representative of the Society at the celebration of the fiftieth Anniversary of the University Museum, Oxford, on October 8, 1908.

GENERAL MEETING.

Held in the Apartments of the Geological Society, June 16, 1908.

Professor H. A. Miers, D.Sc., F.R.S., President, in the Chair.

Fourteen Members and six Visitors were present.

The following papers were read:—

1. On the possible existence of a nickel-iron constituent (Fe_5Ni_3) in both the meteoric iron of Youndegin and the meteoric stone of Zomba: by Mr. L. Fletcher (p. 147).

2. Kaolinization and other changes in West of England rocks: by Mr. F. H. Butler (p. 128).

3. On Schwartzembergite, and the drawing of light-figures: by Dr. G. F. Herbert Smith.

4. The chemical composition of Seligmannite: by Dr. G. T. Prior.

Rock-specimens and slides were exhibited by Mr. Butler in illustration of his paper.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, November 17, 1908.

Principal Miers, D.Sc., F.R.S., President, in the Chair.

Dr. Catherine A. Raisin, Mr. Edward Hopkins, and Dr. S. James Shand, were elected Ordinary Members of the Society.

The following were selected as the dates of meeting for the year

1909:—Tuesdays, January 26, March 23, June 15, November 16, the last to be the Anniversary Meeting.

The Annual Report of Council, drafted by Dr. Prior, was read and approved.

A committee, consisting of the Secretary, the Editor of the Journal, Dr. Tutton, and Mr. Barlow, was appointed to consider the vacancies in the list of Honorary Members.

ANNIVERSARY MEETING.

Held in the Apartments of the Geological Society, November 17, 1908.

Principal Miers, D.Sc., F.R.S., President, in the Chair.

Thirty Members and three Visitors were present.

The elections of Dr. Catherine A. Raisin, Mr. Edward Hopkins, and Dr. S. James Shand to the Ordinary Membership were confirmed.

The scrutineers reported that thirty-three voting-papers had been returned, and that the List as nominated by the Council was approved, namely :—

President—Principal H. A. Miers, M.A., D.Sc., F.R.S.
Vice-Presidents—Prof. W. J. Lewis, M.A., F.C.S.
A. E. H. Tutton, M.A., D.Sc., F.R.S.
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G. Barrow, F.G.S.
J. J. Beringer, A.R.S.M., F.C.S.
F. N. A. Fleischmann, M.A., F.C.S.
H. B. Hartley, M.A., F.C.S.
H. Hilton, M.A.
A. Hutchinson, M.A., Ph.D., F.G.S.
B. Kitto, F.I.C., F.G.S.
G. T. Prior, M.A., D.Sc., F.G.S.
Arthur Russell.
G. F. H. Smith, M.A., D.Sc., F.G.S.
A. P. Young, Ph.D., F.G.S.

The following Annual Report of Council was read :—

The Council has to congratulate the Society on its continued scientific activity and financial prosperity.

During the year four meetings have been held (by kind permission) in the Apartments of the Geological Society, Burlington House, W.; at which twenty papers were read. Two numbers of the Journal (No. 68

published in April, and No. 69 published in November) containing fourteen papers, have been issued during the Session. In this connexion thanks are due to Professor Lewis for the loan of seventeen blocks, and to Dr. F. Zambonini for the loan of three blocks, to illustrate their papers in No. 68 of the Journal; also to Mr. A. Hutchinson for the loan of fifteen blocks to illustrate his paper in No. 69 of the Journal, and to the Editor and Publishers of the 'Naturalist' for printing off from their block 500 copies of the portrait of Dr. Sorby.

During the session 1907–8 the Society has lost by resignation two Ordinary Members (the Earl of Berkeley and Mr. B. H. Woodward), and by death its first President, Dr. Henry Clifton Sorby, while five Ordinary Members have been elected. The total number of members on November 16, 1908, was 127; of whom eighteen are Honorary Members and 109 are Ordinary Members. Of the latter, fifty-one have compounded for their annual subscription.

The financial position of the Society is in a satisfactory state. The balance-sheet of the year ending December 31, 1907, shows that the assets (exclusive of the Library and the stock of the Journal) amounted to £761 18*s.* 3*d.*, and that the liabilities amounted to £73 16*s.* 3*d.* The value of the Stock invested in the names of the Trustees of the Society was on that date £603 10*s.*, corresponding to £11 16*s.* 8*d.* for each Life-Member.

The Society was represented at the celebration of the fiftieth Anniversary of the University Museum, Oxford, by Dr. G. T. Prior.

On the motion of Dr. Tutton, seconded by Mr. Kitto, the Report was adopted, and a vote of thanks was passed to Dr. Prior for his services as Acting Secretary during the illness of Mr. Fletcher.

The dates of meeting for 1909 proposed by the Council were approved.

A vote of thanks to the Council of the Geological Society for permission to meet in the Apartments of the Society was carried.

The following papers were then read :—

1. On Micas from North Wales and Connemara: by Mr. A. Hutchinson and Mr. W. Campbell Smith.

2. On the occurrence of the rare mineral Carminite in Cornwall: by Mr. Arthur Russell.

3. On Russian universal instruments and methods: by Mr. T. V. Barker.

4. On the composition of the Chandakapur meteoric stone: by Mr. H. E. Clarke and Mr. H. L. Bowman.

Owing to the lateness of the hour, the following papers were held over:—

Note on the spontaneous crystallization of drops of solutions as spherulites: by Monsieur Jacques Chevalier (communicated by the President).

Contributions to the study of parallel growths of different substances: by Dr. S. Kreutz (communicated by the President).

On a new method for studying the optical properties of crystals: by the late Dr. H. C. Sorby (communicated by the President).

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, January 26, 1909.

Dr. A. E. H. Tutton, M.A., F.R.S., Vice-President, in the Chair.

Mr. David Bowen, F.G.S., Instructor in Surveying at the School of Mines, Camborne, was elected an Ordinary Member of the Society.

Mr. J. P. De Castro and Dr. J. W. Evans were elected auditors for the accounts of the year ending December 31, 1908.

The Secretary was instructed, on the proposition of Mr. Hutchinson, to ascertain by means of a reply post-card the wishes of the members relative to the hour of meeting of the Society, the choice being between 5 p.m., 5.30 p.m., and 8 p.m.

GENERAL MEETING.

Held in the Apartments of the Geological Society, January 26, 1909.

Dr. A. E. H. Tutton, M.A., F.R.S., Vice-President, in the Chair.

Twenty-three Members and three Visitors were present.

The election of Mr. David Bowen to the Ordinary Membership was confirmed.

The following papers were then read:—

1. On the identity of Poonahlite with Mesolite: by Dr. H. L. Bowman (p. 216).

2. Contributions to the study of parallel growths of different substances: by Dr. S. Kreutz (communicated by the President) (p. 232).

3. 'Cross-planes' in twin-crystals: by Dr. J. W. Evans.

4. The comparison of the refractive indices of minerals in thin sections, when the directions of vibrations are not parallel: by Dr. J. W. Evans.

5. Some additional localities for Idocrase in Cornwall: by Messrs. G. Barrow and H. H. Thomas (p. 238).

6. Detrital Andalusite in Tertiary and Post-tertiary sands: by Mr. H. H. Thomas (p. 241).

7. Note on the spontaneous crystallization of drops of solutions as spherulites: by Monsieur Jacques Chevalier (communicated by the President) (p. 224).

8. On a new method for studying the optical properties of crystals: by the late Dr. H. C. Sorby, Past-President (communicated by the President) (p. 189).

9. The energy of twin-crystals: by Mr. H. Hilton (p. 245).

Mr. Hutchinson exhibited and explained a new form of protractor, designed by Professor V. Goldschmidt, for use in the preparation of stereographic and gnomonic projections of crystals. Specimens were exhibited in illustration of the papers of Dr. Bowman, and Messrs. Barrow and Thomas; and also other specimens submitted by Mr. Arthur Russell.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, March 23, 1909.

Principal Miers, D.Sc., F.R.S., President, in the Chair.

The death of Mr. Hudleston, Past-President, was announced, and the President was requested to send a letter of condolence to the widow.

The resignation of Mr. John Parkinson was accepted.

Mr. Henry Dewey, F.G.S., was elected an Ordinary Member.

Announced that the Royal Society had agreed to contribute the sum of £10 from the Publication Fund for the cost of the publication of the posthumous paper of Dr. Sorby.

The audited balance-sheet for the year ending December 31, 1908, was approved.

Mr. Spencer reported that he has prepared on behalf of the Society 1076 slips relative to mineralogical, crystallographical, and petrographical papers and books published in the United Kingdom during 1908 for the International Catalogue of Scientific Literature.

The Secretary reported that the Members who were not indifferent relative to the hour of meeting had voted as follows :—

Five for 8 p.m.; twelve for 5.30 p.m.; four for either 5 or 5.30; sixteen for 5 p.m. It was resolved to select 5.30 p.m. for the hour of meeting, and that the first meeting at the earlier hour be the Anniversary Meeting, on November 16, 1909.

GENERAL MEETING.

Held in the Apartments of the Geological Society, March 23, 1909.

Principal Miers, D.Sc., F.R.S., President, in the Chair.

Twenty-five Members and one Visitor were present.

The election of Mr. Henry Dewey to the Ordinary Membership was confirmed.

It was announced that the hour of meeting would be changed to 5.30 p.m., the first meeting at the earlier hour being the Anniversary Meeting on November 16, 1909.

The following papers were read :—

1. On a stage-goniometer for use with the Dick-pattern of microscope : by Professor H. L. Bowman.

2. The electrostatic separation of minerals : by Mr. T. Crook (p. 260).

3. On the identity of Guarinite and Hiortdahlite : by Dr. F. Zambonini (with chemical analysis by Dr. G. T. Prior) (p. 247).

4. Note to a paper 'On the comparison of refractive indices of minerals in thin sections' : by Dr. J. W. Evans.

MINERALOGICAL SOCIETY.

ABSTRACT OF RECEIPTS AND PAYMENTS FROM JANUARY 1 TO DECEMBER 31, 1908.

Receipts.	£ s. d.	£ s. d.
Balance from 1907		112 12 8
Subscriptions—(1) current	49 7 0	
(2) arrears	6 6 0	
(3) advance	1 1 0	
		56 14 0
Entrance fees and Compositions		4 4 0
Sale of publications—		
By Publishers	31 16 0	
By G. Savigar	10 13 7	
,, ,, (from Max Weg)	6 0 9	
		48 10 4
Dividends on Stock		17 6 11
		£239 7 11

Payments.	£ s. d.	£ s. d.
Printing Magazine (No. 67)	43 9 10	
Authors' copies	8 16 6	
Illustrations	5 14 0	
		58 0 4
Printing Magazine (No. 68)	33 12 0	
Authors' copies	5 12 3	
Illustrations	5 14 6	
		44 18 9
Printing Magazine (No. 69)	27 6 0	
Authors' copies	5 16 6	
Illustrations	4 5 0	
,, (Portrait of Sorby)	8 0	
Special wrappers	6 6	
		38 2 0
International Catalogue of Scientific Literature, cards		8 0
Miscellaneous Printing		6 5 9
Editor's Honorarium (1907)		10 10 0
G. Savigar for care of Stock (1907)		1 1 0
Porter's Fee		1 0 0
Postage and Parcels—		
Printers (Magazine)	6 17 1	
,, (Authors' copies)	9 7	
G. Savigar (1907)	3 6	
Hon. Secretary (1907)	3 7	
Hon. Treasurer (1907)	7 7	
		8 1 4
Investments		33 1 11
Bank Charges		0 1 0
Balance at Bank	37 4 1	
,, in Office	13 9	
		37 17 10
		£239 7 11

Examined and compared with the vouchers, and found correct.

(*Signed*) JOHN W. EVANS
J. PAUL DE CASTRO } Auditors.

Liabilities.	£	s.	d.
Owing for Editor's Honorarium (1908)	10	10	0
,, G. Savigar for care of Stock (1908)	1	1	0
,, Do. for postage (1908)	0	4	6
,, Hon. Secretary for postage (1908)	0	7	5
,, Hon. Treasurer ,, ,, (1908)	0	9	3
Balance of assets over liabilities	696	18	7
	£709	10	9

Assets.	£	s.	d.	£	s.	d.
Balance at Bank				37	4	1
,, in Office				0	13	9
Consols (£750 19s. 10d., valued at £84)				630	0	0
Sale of Publications—						
Owing from Publishers	26	4	6			
,, G. Savigar	10	3	5			
				36	7	11
Subscriptions in arrear, valued at				5	5	0
				£709	10	9

The number of Life Members on December 31, 1908, was 51.

The stock of Publications and the value of the Library are not included in the above assets.

(*Signed*) W. P. BEALE,
Hon. Treasurer.

March 19, 1909.

THE MINERALOGICAL MAGAZINE

AND

JOURNAL OF

THE MINERALOGICAL SOCIETY.

No. 70. July, 1909. Vol. XV.

On a new method for studying the optical properties of crystals.[1]

By the late Henry Clifton Sorby, LL.D., F.R.S.

[Communicated by Principal Miers, and read January 26, 1909.]

BEFORE treating of the subject before me, I must describe its history. At a soirée of the Royal Society on April 25, 1877, I showed a number of specimens illustrating a new class of optical properties, applicable to the identification of minerals. These greatly

[1] The MS. of this paper was finally prepared for press by Dr. Sorby during his last illness. It contains the details and complete account of his work, of which preliminary accounts were published in the first two volumes of the Mineralogical Magazine under the following titles :—

'On a simple method of determining the index of refraction of small portions of transparent minerals.' 1877, vol. i, pp. 97–98.

Presidential address. [Determination of refractive indices in mineral plates, &c.] 1877, vol. i, pp. 193–208, with plate VII.

'On the determination of minerals in thin sections of rocks by means of their indices of refraction.' 1878, vol. ii, pp. 1–4.

'Further improvements in studying the optical characters of minerals.' 1878, vol. ii, pp. 103–105.

The method he describes for determining refractive indices is identical in principle, though worked out in far greater detail, with that given by the Duc de Chaulnes in 1767 for singly-refracting substances ; but, as may be gathered from a remark in the last of the papers quoted above, the method was devised quite independently by Dr. Sorby.

The paper is now published with the aid of a grant from the Government Publication Grant administered by the Royal Society.

An obituary notice, with portrait, of Dr. Sorby appeared in the last number of this magazine (vol. xv, p. 180).

interested the late Sir G. G. Stokes, Bart., and led to a considerable amount of correspondence between us; and he communicated a paper to the Royal Society on the mathematical part of the subject,[1] and I sent a short one[2] on my apparatus and observations. This was admitted to be very imperfect, since the crystals examined, though showing the general facts perfectly well, had not been cut so as to be suitable for such quantitative measurements as could be compared with Stokes's theoretical determinations. In my short paper I therefore said that I intended to prepare a variety of crystals, accurately cut in suitable directions, and to make use of fresh means to correct sundry small instrumental errors. All this I carefully carried out, and wrote a paper almost finished and labelled 'Manuscript for the Royal Society'. I then left home for some time, and a number of important circumstances turned up to draw away my attention, and it was not till after thirty years that I was astonished to find the manuscript.

It is now so long since the papers by Stokes and myself were published, that it seems desirable to describe the older and newer apparatus employed, added to a first-class Smith & Beck's microscope. These are as follows:—A scale and a vernier attached to the stand and body of the microscope, so that the up and down movement may be measured to $\frac{1}{1000}$th inch. Underneath the stage a glass plate with two sets of lines $\frac{1}{100}$th of an inch apart, ruled at right angles to one another, brought to focus at about the level of the stage by the achromatic condenser. Close to the glass plate is an iris-diaphragm, so that a circular hole of variable size can be brought to focus along with the ruled lines. Below can be inserted or withdrawn a Nicol's prism, capable of rotation. A cap fitting on the object-glass with a small hole to reduce the residual spherical aberration; and another cap to cut off half the area of the object-glass in any desired direction, to detect and determine the plane of polarization of any beam that has passed through the crystal under examination.

These simple appliances open out a wide field for study in connexion with mineralogy. To quote from Stokes's paper: before the time of Fresnel it was thought that one of the rays in a biaxial crystal obeyed the ordinary laws of refraction. To prove that this was not the case required skill on the part of the optician who worked the crystal. 'It is interesting to find that the extraordinary character of the refraction of

[1] G. G. Stokes, 'On the foci of lines seen through a crystalline plate.' Proc. Roy. Soc. London, 1877, vol. xxvi, pp. 386–401.

[2] H. C. Sorby, 'On some hitherto undescribed optical properties of doubly refracting crystals.—Preliminary notice.' Ibid., pp. 384–386.

both rays in a biaxial crystal admits of being established by such comparatively simple methods of observation as those adopted by Mr. Sorby.'

In the following original paper my chief aim was to show that my measurements and the general facts agree so closely with Stokes's mathematical calculations as to prove that all are substantially correct, though there may be a few small residual errors. Though tempted to add to the paper, it may be well to leave it nearly as it was, as being more in accordance with what had met with Stokes's approval. *The following is the paper written thirty years since*:—

Determination of the True Indices.

Professor Stokes's theoretical deductions and my own observations clearly prove the importance of distinguishing between real and apparent indices, and show in what circumstances, and in what manner, the true indices may be determined. There is no difficulty whatever in the case of unifocal images, since the apparent index is the true index (μ), no matter what may be the direction in which the section is cut; but in the case of bifocal images the connexion between them is somewhat complex, unless the section is in a suitable direction, and even then some calculation may be necessary. The true index (μ') of the single extraordinary ray of crystals having only one bifocal image cannot be conveniently determined unless the section be either parallel or perpendicular to the axis, in which latter case the index (μ) of the ordinary ray must be known; the two images being distinguished by using the semicircular stop in front of the object-glass, already explained. If A be the apparent index, μ' can be calculated from the equation $\mu' = \sqrt{A\,\mu}$. When the section is parallel to the axis, the apparent index (a) for lines parallel to the axis of the crystal and perpendicular to the plane of polarization is the true index (μ') of the extraordinary ray, which may also be calculated from the other apparent index (b) by means of the following equation, $\mu' = \frac{\mu^2}{b}$. We thus obtain its value by two different measurements, the mean of which may be adopted, unless there be some doubt as to the section being parallel to the axis, since a slight inclination would reduce the value calculated from b much more than that determined directly from a. I give examples of the application of these methods.

If the crystal has two bifocal images, polarized in opposite planes, giving the four apparent indices $\begin{matrix} a & c \\ b & d \end{matrix}$, the true values of the three indices of refraction, μ, μ', μ'', may be either directly observed or calculated, if the section be in the plane of any two of the three axes of the crystal. In this case a, b, c, d become respectively $\frac{\mu''^2}{\mu'}$, μ', μ, $\frac{\mu''^2}{\mu}$.

In each of these images the apparent index for lines perpendicular to the plane of polarization (b) and (c) is a true index, and the value of μ''^2 may be determined from a and from d by means of the following equations, $\mu'' = \sqrt{a\,\mu'}$ or $\sqrt{d\,\mu}$.

If the section was accurately cut, and the observed values of a, b, c, and d strictly correct, we ought therefore to have $\frac{a}{d} = \frac{c}{b}$; but, since errors can be scarcely avoided, this relation may not be found to be exact. Assuming that the errors are equally distributed over all the four determinations, we may, however, so divide between a, b, c, and d the discrepancy thus found, as to obtain the corrected values a, b, c, d, in which the relation $\frac{a}{d} = \frac{c}{b}$ is strictly true. In this manner we make use of four different observations to obtain the most probable mean values of the three indices.

If a crystal having two bifocal images be cut in the plane of only one axis, only that one of the three indices which corresponds to this axis can be determined by any simple means. It is that which is observed from the system of lines parallel to the axis, in the image polarized in a plane perpendicular to it. If, however, the section be oblique to all the axes, the true value of none of the indices can be determined, either by direct observation or by any simple calculation.

As an example I give the corrected apparent indices in the case of two sections of aragonite, and the true indices deduced from them.

Perpendicular to the axis.

1·387 1·677
1·675 1·385

μ = 1·677
μ' = 1·675
$\mu'' = \sqrt{1{\cdot}387 \times 1{\cdot}675} = 1{\cdot}524$, or $\sqrt{1{\cdot}677 \times 1{\cdot}385} = 1{\cdot}524$.

Parallel to the axis, perpendicular to the twin-lamellae.

1·655 1·515
1·690 1·846

μ = 1·690

$\mu' = \sqrt{1{\cdot}655 \times 1{\cdot}690} = 1{\cdot}672$, or $\sqrt{1{\cdot}515 \times 1{\cdot}846} = 1{\cdot}676$.

μ'' = 1·515

Whence the means are:—

$\mu = 1{\cdot}683$, $\mu' = 1{\cdot}674$, and $\mu'' = 1{\cdot}520$.

Measurement of the Indices of Refraction.

In order to determine the value of their indices of refraction with such an instrument as I have described, it is requisite to measure the thickness (t) of the substances, and the displacement (d) of the focal length, due to the light passing through them. The index of refraction of each specimen can then be calculated from the equation $\mu = \frac{t}{t-d}$. The thickness (t) of the specimen is determined by first adjusting the focus to particles of dust on the supporting glass, reading off the position on the scale, and then adjusting the focus for particles of dust on the upper surface of the mineral, and reading off this position. The difference in the readings gives the thickness. In order to determine the displacement of the focus when looking through the mineral I make use of a grating with two sets of parallel lines $\frac{1}{100}$th of an inch apart, ruled at right angles to one another on the same surface of a plate of glass, which is fixed some distance below an achromatic condenser with a small stop, and the image thrown just below the upper surface of the glass slip supporting the mineral. This is far better than having the lines on a plate placed on the stage, since we can move the object without altering the position of the lines. By this arrangement we see sharp and well-defined lines, that cannot be mistaken for any others. These of course are first viewed through the supporting glass alone, and afterwards through the mineral, the focus in both cases being carefully adjusted for the centre of the field. The decrease (d) in the focal length is given by the difference between the two sets of readings. If the upper surface of the mineral is covered with thin glass cemented with Canada-balsam, its thickness is measured, and, in calculating out the results, allowance is made for it in the following manner. The index of refraction of the covering glass combined with a thin layer of Canada-balsam, being about 1·53, the focal length is increased 0·53 for every 1·00 in the apparent

thickness of the glass, as measured by looking through it. This is known from the difference between the focal points of dust on the upper surface and of small scratches or other marks on the surface of the mineral, and 0·53 of its value must be deducted from both t and d; the value of t being of course reckoned from the apparent upper surface of the mineral, and not from the top of the glass cover. Care must be taken to avoid any errors which might result from moving the stage of the microscope. In order to obtain strictly accurate measurements, all parts of the instrument should be well made, and a monocular arrangement used, since with a binocular the focal adjustment may not be the same for both images.

I have usually employed a No. 2 eye-piece and a $\frac{2}{3}$-inch object-glass, stopped down to an aperture of 13°, to avoid any effects of spherical aberration. A difference in adjustment of $\frac{1}{1000}$th of an inch is thus easily recognized. We must, however, not forget that the eye itself has some range in focal adjustment, and, even with every care, individual measurements may differ by $\frac{1}{1000}$th of an inch. The values of t and d might thus each vary by $\frac{2}{1000}$ths of an inch; and, if the variation were in opposite directions, $t-d$ might vary by as much as $\frac{4}{1000}$. This source of error may to a great extent be overcome by making a number of measurements and taking the mean, which then might usually not differ more than $\frac{1}{10000}$th of an inch from the truth. If the specimen examined be not less than $\frac{1}{4}$ inch thick, and in every other respect suitable for the purpose, the errors in the value of the index should be confined to the third place of decimals. Some of the specimens described in this paper are not, however, in every respect suitable for accurate measurements, and the errors in the *actual values* of the index may extend to the second place of decimals. For the general purposes of this paper this is of comparatively little importance, since the true value of the indices of different specimens of the same mineral may vary as much. The *relative values* of those measured in the *same* specimen are, however, dependent on *only two* sets of measurements, and therefore the chances of error are reduced to at least one-half. In some cases I think that the difference between the indices may be relied upon to another decimal point further than their actual values. I am anxious to call attention to this, since, though I look with suspicion on the absolute values of some of the indices given in this paper, I think that the relative values of those for any one single specimen are quite sufficiently accurate to establish the general principle of my subject.

In order to ascertain how far the method may be relied on, Professor

Stokes has determined the index of refraction of three different specimens of glass by the usual method, and I have determined them in the manner described above. The best specimen for the purpose was a light crown-glass. I took the mean of fifteen separate measurements. On using the light transmitted by blue glass, I found that the dark lines were scarcely visible. I also found that there was no sensible difference in the focal length when I used simple gas-light or the same transmitted through red glass which cuts off all rays more refrangible than D. This is perhaps because the focus-giving power of the red end of the spectrum of gas-light overpowers the effect of the blue end. However, to make sure I have in most cases used the red glass, and then the indices of refraction which I give represent those corresponding to about the centre of the red. I obtained for the index of this crown-glass 1·502. Professor Stokes obtained for the chief line of lithium 1·5011, and for that of sodium 1·5040. The mean of these would very well represent the centre of the red, and gives 1·5025, which thus differs very little from my result. In the case of the other glasses this same mean was found by him to be for one 1·6164, and for the other 1·8450. My results, deduced from only four or five separate measurements, were 1·620 and 1·838, one being thus rather too great and the other rather too little.

We therefore see that by eliminating the errors due to the slight range in focal adjustment, by taking the means of a number of measurements, a very satisfactory result may be obtained, and we also see that, when only a few observations are made, there may be a very decided error in excess or the reverse. These comparisons, however, show that the general principle is correct with suitable specimens, and that indices may be thus determined sufficiently accurately for the purpose to which I am about to apply them.

Nearly all the sections of the minerals examined were made by myself. Some of the calcite, aragonite, barytes, and fluor, were specially cut for the present purpose, but many of the rest were prepared long ago in connexion with various other subjects and were not all as good as could be desired. Except in a few cases the sections were cut more in relation to crystal forms than to the optic axes, and I have generally endeavoured to work them parallel to the commonest faces or well-marked cleavage, so that the results might be easily applied to the study of crystals in their natural state, or to portions obtained by cleavage. When I speak of the axes, I therefore generally refer to the crystallographic, and not to the optic, axes. It appeared to me desirable thus to adapt the subject to practical mineralogy, even though this made the

results less suitable for comparison with Professor Stokes's theoretical deductions. I have also given the directions in which the sections are cut, rather than those along which the light passes, since, though the mean direction of the latter is usually perpendicular to the former, the special results of my method mainly depend upon slightly divergent rays being collected by an object-glass.

In studying the optical characters of minerals I have found it extremely useful to have an iris-diaphragm fixed some distance below the achromatic condenser, which can at pleasure be inserted or reversed without disturbing the grating. An image of a hole of any desired magnitude can thus be examined through the minerals. In some cases it is very necessary to have this hole extremely small, and to employ a comparatively high magnifying power. Small holes, made in thin black paper with a fine needle, may also be used with advantage below the condenser. It must be borne in mind that the separation and distortion of the images of the hole depend upon the thickness of the mineral, the direction of the section, the intensity of its double refraction, the size of the hole, and the magnifying power used. In describing the characters of the various minerals I shall first describe the varying appearances of such a hole, the principal of which are shown in the following illustration (p. 214), and then the phenomena observed with the rectangular grating.

Crystals with no Double Refraction.

In looking at the circular hole through crystals which have no double refraction, a simple, single hole is seen at one particular level and in perfect focus all round, as shown by fig. 1. The lines of the grating are all seen at one single focal point, no matter what may be the azimuth of the crystal. Such crystals are truly unifocal. The value of the index of refraction for the simple ordinary ray can easily be determined, but it may be well here to say that I have very strong reason to believe that slight differences in the chemical composition of different specimens of the same mineral give rise to corresponding differences in the value of the index. This appears to be the best explanation of the small but yet decided differences between some of my own measurements *inter se* and between them and the determinations of other experimenters by methods previously adopted. As illustrations of crystals having these characters I refer to fluor, leucite, and garnet. Thus, for two different specimens of fluor, I obtained 1·442 and 1·446. Previous observers by the old method give 1·433 and 1·436.

Crystals with one Axis of Double Refraction.

The phenomena vary much according to the inclination of the plane of the section to the principal axis of the crystal. Iceland-spar is of course the best type. My sections vary from about 0·3 to 0·4 inch in thickness.

Calcite. According to previous observers, the indices of refraction for medium red light are for the ordinary ray (μ) 1·656, and for the extraordinary (μ') 1·485.

1. *Section cut perpendicular to the principal axis.*—In looking at the circular hole, along the line of the axis, where there is no double refraction for perfectly parallel rays, I was very much surprised to find that there are two focal points, widely separated. On adjusting for one focus the circular hole is seen not in any way distorted and in perfect focus all round. It is, however, surrounded by a nebulous larger circle, which is really the image of the second circle seen out of focus, as shown by fig. 2. On altering the focal adjustment the true bright image expands and the nebulous circle contracts until we obtain a simple circle with no definite outline, and finally we come to the true focal point of the second image surrounded by the other circle seen out of focus. As far as the general appearances are concerned, the phenomena are just as though we were looking at two equal circular holes in black paper fixed opposite to one another on the opposite sides of a piece of glass.

When the section is cut exactly perpendicular to the axis, and not in any way inclined, so that the line of vision is directly along the axis, the two holes lie exactly one over the other, and in neither is the light polarized. In this position, without any of the special arrangements described below, it is therefore impossible to distinguish the ordinary from the extraordinary way. However, if the section be somewhat inclined, so that the images are seen separated, both are polarized, and the ordinary ray can be distinguished by its being polarized in the plane of the principal axis, which may be known by being that along which the holes are separated.

On examining the grating we see that there are two different focal points, wide apart, at which the two systems of lines at right angles to each other are in perfect focus at the same time, quite independently of their azimuth. These two images, one really and the other apparently unifocal, cannot be conveniently distinguished by inclining the section, since that alone is sufficient to make a true unifocal image appear bifocal. I am indebted to Professor Stokes for suggesting a method which enables us to ascertain which is due to the ordinary and which to the extra-

ordinary ray. If a cap with a narrow slit be placed over the object-glass, so that the images are formed merely by a band of light extending over a diameter, that due to the ordinary ray is polarized in the plane of the slit, and that due to the extraordinary ray is polarized in the opposite plane. If this slit be too narrow, the objects are badly defined, and, if too broad, the two images are very imperfectly polarized. I find that with my $\frac{2}{3}$-inch object-glass a slit about $\frac{1}{50}$th of an inch wide gives a good medium result, since the definition is sufficiently good and the two beams sufficiently polarized to remove all doubt as to which is which. The slit should be arranged parallel to one of the systems of lines. That system cannot be seen at one definite focus, but along a strip passing through the centre of the field in the direction of the slit; the lines perpendicular to it are well defined at two different foci, and the pencils of light giving the images are polarized in the two opposite planes.

The disadvantages arising from the definition with the narrow slit being good only over a narrow band have induced me to contrive another method, which not only serves to distinguish the two images by the difference in their plane of polarization, but also clearly shows that one is not truly unifocal. I employ a cap over the object-glass, stopping off exactly one-half of the front lens, which thus has a semicircular aperture, the diameter being arranged parallel to one or other of the two sets of lines in the image of the grating. With such an object-glass the definition is not materially impaired, but the light passing somewhat obliquely through the mineral under examination gives rise to results which are to some extent as though the section were cut not quite perpendicular to the axis. In the case of the section now being described the ordinary ray is well polarized in a plane perpendicular to the edge of the semicircular stop, and the extraordinary ray in the opposite plane. The ordinary ray remains unifocal, whereas the extraordinary ray may be seen to have to a slight but yet decided extent the bifocal character more particularly described in the sequel.

The indices of refraction, measured in the manner described above, were found to be 1·659 for the ordinary, and 1·335 for the extraordinary ray, which, however, is only an apparent index. The true index of the extraordinary ray is 1·487, and according to Professor Stokes's theoretical deductions the above apparent index should be $\frac{(1\cdot487)^2}{1\cdot659} = 1\cdot333$.

This specimen was cut with very great care, and is free from every fault. Such a close agreement between theory and observation appears

to me to prove very clearly that the general principles of both must be very nearly, if not absolutely, correct. Conversely, the index for the extraordinary ray, calculated from the above data, should be $1{\cdot}659 \times 1{\cdot}335 = 1{\cdot}488$.

2. *Section parallel to the cleavage.*—Looking at a hole previously arranged in the centre of the field of the microscope, it is seen to be widely separated into two as shown by fig. 3, one remaining in the centre, and the other thrown on one side somewhat distorted and apparently lying at a lower level. This difference between the ordinary and the extraordinary images is thus seen to very great advantage. In studying sections of minerals cut so as to show double refraction, it is, however, best to employ a Nicol's prism over the eye-piece, in order to examine separately the two rays polarized in opposite planes. No ordinary nicol, with sloping ends, should be placed between the condenser and the grating, since it makes the image to some extent bifocal. Arranging the analyser so that the plane of polarization is parallel to the principal axis of the crystal under examination, the central image of the circular hole, due to the ordinary ray, is seen to be well defined all round, and to have one simple and perfect focus. On the contrary, when the plane of polarization of the nicol is perpendicular to the principal axis, the displaced image, due to the extraordinary ray, is seen to be distorted in a remarkable manner. Its true size and shape cannot be seen at any adjustment of the focus, and on careful examination it is found that there is no true focus except for those parts of the circumference which are either parallel or perpendicular to the axis of the crystal, and that these lie in very different planes. If the hole be small, it is also seen to be much distorted. Adjusting the focus for those opposite sides of the circumference which are parallel to the axis, the hole is seen to be drawn out into a band in the line of the axis, having well-defined parallel sides, but ending in ill-defined extremities, one coloured blue and the other red. On drawing back the body of the microscope this band changes into a circular hole, several times larger than the real one, fringed on two sides with colour, and then changes into a band elongated in a direction perpendicular to the former. The sides are, however, never seen perfectly well defined, because they are fringed with colour, unless more or less perfectly monochromatic light is used for illumination.

On examining the grating when the nicol is so arranged that only the ordinary ray is transmitted to the eye, the image is seen to be truly unifocal. Both sets of lines are visible at one perfect focus, no matter what may be their azimuth, and the index of refraction is found to be

1·657, thus agreeing closely with the previous determination from a portion of the same specimen cut in another direction. On the contrary, when the nicol is so arranged that only the extraordinary ray passes, and the lines of the grating are parallel and perpendicular to the axis of the crystal, there are two widely separated focal points, at each of which *only one system* of lines can be seen. That which is parallel to the axis is well defined, and indicates an index of refraction of 1·412, whilst that system which is perpendicular to the axis is not seen as sharp lines, but as coloured bands, unless almost monochromatic red light be used, and then the apparent index of refraction is 1·578. The extraordinary image is therefore truly bifocal.

3. *Section cut nearly parallel to the principal axis.*—On examining a small circular hole we can see that neither image is displaced from the centre, but that they differ from one another most completely in other respects. Arranging the nicol so that only the ordinary ray passes to the eye, the circular hole is seen in perfect focus all round, and not at all modified in shape or size; but when the extraordinary ray passes to the eye, the hole is drawn out into a long band at two widely separated focal points as shown by figs. 4 *a* and 4 *b*, much in the same manner as previously described, only that it is elongated nearly twice as much as in the case of a section parallel to the cleavage, and almost entirely free from the coloured fringes. Judging from what is seen when the hole is small, a bright or dark point would, at two different and widely separated foci, be elongated into a line, which at one focus would be parallel to the axis, and at the other focus perpendicular to it, the elongation in the latter case being somewhat less than in the former. In intermediate positions we can see nothing but one or other of these lines more or less completely out of focus, perhaps so much so as to be practically invisible.

The facts just described make it easy to understand the peculiar phenomena observed when the grating is examined. Arranging the nicol so that only the ordinary ray passes to the eye, the two systems of lines are seen at the same focus independent of their azimuth, the image being thus perfectly unifocal. In the specimen examined the index of refraction was found to be 1·671. Many very careful measurements all agree, and I can explain this higher index only by supposing that the chemical composition of this specimen is not exactly the same as that of those previously described. In the case of the extraordinary image, the lines parallel to the axis give for the index 1·495, which exceeds the value of that for the extraordinary ray, deduced from the former

specimen, by about the same amount as in the case of the ordinary ray. At all events we clearly see, that for lines parallel to the axis, the apparent index is the true index of the extraordinary ray. On the contrary, the apparent index for the lines perpendicular to the axis is no less than 1·851 or thereabouts. They are not perfectly well defined, and therefore it cannot be determined with any great accuracy. There is, however, no doubt whatever that it is far greater than that of the ordinary ray, since the lines are seen in focus when those due to the ordinary ray are completely invisible. According to Professor Stokes's theoretical deductions, it should be $\frac{(1\cdot671)^2}{1\cdot495} = 1\cdot868$. The difference between these determinations may safely be attributed to the fact of the section not being cut exactly parallel to the axis, having been made for general observation, when the leading facts were not understood, and not with the great care necessary to accurately verify this theoretical deduction. The error in direction would certainly have comparatively little effect on the value of the true index, deduced from lines parallel to the axis.

As previously named, the two systems of lines seen with the ordinary ray are perfectly distinct, no matter what may be their azimuth to the axis of the crystal. This is, however, not the case with those seen by means of the extraordinary ray. Having arranged them parallel and perpendicular to the axis, and having adjusted the focus to one or other system, on rotating the lines it will be seen that a very small change in the azimuth makes them appear broader and less distinct; and if, as in the specimens now being described, the spar be $\frac{3}{10}$ths of an inch in thickness, a still further change in the azimuth causes them to vanish entirely. The reason of this is very obvious. Each point in every line is drawn out into a line at two different foci, either in the direction of the axis or at right angles to it; and if these overlap, as they do when the lines are themselves in one or other of those directions, well defined lines are seen. On the contrary, if each point is drawn out in a direction considerably inclined to that of the lines, they are, as it were, spread over a surface many times greater than their true breadth, and so diluted with white light as to be completely invisible. It is to images having these characters that I apply the term *bifocal*.

It will thus be seen that this method of studying crystals shows in a most striking manner the difference between the ordinary and extraordinary rays. In the case of the ordinary ray, the phenomena differ in no way from what would be seen in looking through a piece of glass, or

indeed in looking at a hole or grating without any intervening object. On the contrary, the phenomena seen by means of the extraordinary ray are most strikingly different, and one cannot help being at first greatly surprised to find that the two systems of lines ruled on exactly the same plane, seen through a perfectly transparent substance with parallel sides, lie as it were at two entirely different levels, and are visible only at one particular azimuth, and disappear on being rotated to other azimuths. Except that the light is polarized, this bifocal character of the extraordinary ray closely corresponds to the effects produced by inserting a cylindrical lens in front of the object-glass.

The relations of the above real and apparent indices will be better understood by collecting them together into a table, in which I give the best combined results of observation and theory.

Directions of the Sections.			
Perpendicular to the axis.		Parallel to the cleavage.	Parallel to the axis.
$1{\cdot}658\,(\mu)$	... ...	$1{\cdot}658$ ...	$1{\cdot}658$
$1{\cdot}332\left(\frac{\mu'^2}{\mu}\right)$	Line of axis ...	$1{\cdot}412$ ...	$1{\cdot}486\,(\mu')$
	Perpendicular to axis	$1{\cdot}578$ ...	$1{\cdot}850\left(\frac{\mu^2}{\mu'}\right)$

According to this, the maximum difference between the foci in the bifocal image is 0·1324 of the thickness of the specimen under examination.

It will thus be seen that, whilst the index of the ordinary ray remains single and constant, that of the extraordinary ray, which is single and at a minimum in the case of the section perpendicular to the axis, breaks up into two, that for lines parallel to the axis gradually increasing until it becomes equal to the normal index, whilst that for lines perpendicular to the axis increases much more rapidly, until it attains the very high apparent index 1·850, which is about the same as the real index of dense flint-glass.

Other Minerals having one Axis of Double Refraction.

As examples of other minerals belonging to this division I would refer to parisite, proustite, zircon, and quartz.

Parisite (fluo-carbonate of cerium, lanthanum, and didymium). According to Senarmont, the index of refraction for the ordinary ray is 1·569, and for the extraordinary is 1·670; the double refraction being

positive. My section, nearly perpendicular to the axis, shows extremely well two unifocal images, at two widely separated focal points, and gives the indices 1·74 and 1·99. The former must be that of the ordinary ray, and that of the extraordinary $1{\cdot}74 \times 1{\cdot}99 = 1{\cdot}86$. The great excess in both cases over Senarmont's results cannot, I think, be due to any error in my observations, since those made by different methods and at different times closely agree. Perhaps it is really due to some variation in the relative amounts of the bases in such a complex mineral. A comparison of these results with those obtained from the analogous section of calcite, shows very clearly the difference between positive and negative double refraction. They are as follows:—

	Double Refraction.	Ordinary.	Apparent extraordinary.
Calcite ...	Negative ...	1·659 ...	1·335
Parisite ...	Positive ...	1·74 ...	1·99

The apparent extraordinary index is thus abnormally small when the double refraction is negative, and abnormally large when positive.

Zircon cut obliquely to the axis shows the images of the circular hole widely separated. The ordinary ray is unifocal, and gives for the index about 1·975. The extraordinary ray is bifocal, and gives for lines parallel to the axis the index 2·083, and perpendicular to it 1·972. Neither of these can be the true index of the extraordinary ray, but since that for lines parallel to the axis is greater than that of the ordinary ray, they prove that this mineral has positive double refraction.

Quartz has such a weak double refraction that it is interesting chiefly as showing that it can be recognized by the method now under consideration. In a section $\frac{1}{5}$th of an inch thick, cut perpendicular to the axis, it is just possible to recognize two foci, and in one cut parallel to the axis to see that there is both a unifocal and a bifocal image. The true index of refraction of the extraordinary ray, deduced from lines parallel to the axis, exceeds by about 0·01 that of the ordinary ray, thus showing that this mineral has positive double refraction. My measurements indicate a well-marked difference in the actual value of the indices in different specimens, varying from about 1·55 to 1·56, that of the extraordinary ray being about 0·01 more in each case.

Proustite (ruby-silver-ore). A section parallel to the principal axis shows extremely well similar phenomena to those described in connexion with calcite. The index for the ordinary ray, polarized in the plane of the axis, is 2·98. The extraordinary ray, polarized in the opposite plane, gives for the true index 2·66, and for the apparent index for

lines perpendicular to the axis 3·23. According to Professor Stokes's theory this should be $\frac{(2\cdot93)^2}{2\cdot66} = 3\cdot22$, which is as close an agreement as could be expected from indices determined by means of only a small crystal.

Tourmaline. A green, very dichroic specimen is interesting from the fact that it transmits only the extraordinary bifocal image, and thus appears to have no ordinary ray, which, however, is visible enough in less dichroic specimens.

Crystals with two Axes of Double Refraction.

Aragonite. On the whole I do not think I can select a better type than this mineral, because its double refracting power is so great, though the alternation of twin-crystals, shown by slight reflection at the planes of contact, and the intimate combination of similar twins, not visible by ordinary light, make it extremely difficult to determine the indices accurately. They also give rise to curious irregularities in the various phenomena now to be described. According to previous observers, the three true principal indices of refraction are 1·689, 1·684, and 1·531.

1. *Section cut perpendicular to the principal axis.*—My specimen is about $\frac{2}{5}$ths of an inch thick, sufficiently free from visible thin twin-plates, but yet by no means having a perfectly regular structure. On looking at the small circular hole, we at once see that the properties of the crystal are totally unlike anything so far described. As in the case of calcite cut perpendicular to the axis, there are two widely separated focal points, but instead of each showing a simple, well-defined circle, each shows a cross, due to the circles being elongated into two bands at right angles to one another. It is only in those parts of the specimen which are the most free from crystalline irregularities, that the cross is anything like as regular as shown in fig. 5. In most parts the arms are broken up into irregular branches, which appear to be due to the combination of two sets at slightly different azimuths, caused by the alternation of the twin-plates, which are invisible with ordinary light. In the case of calcite neither of the two images is polarized, and a Nicol's prism over the eye-piece produces no effect; whereas in the case of aragonite at the proper azimuths one pair of the opposite arms of the above-named cross or the other pair is extinguished, thus proving that both beams are polarized, one in the plane of the resultant axes, and the other perpendicular to it.

On arranging the nicol so that each image may be examined alone, both are seen to have the same bifocal characters as those of the extraordinary ray in a section of calcite cut parallel to the axis. There are two widely separated focal points about 0·1250 of the thickness of the specimen apart, at which the circular hole is drawn out into a band, which at one focus is parallel and in the other perpendicular to the plane of polarization.

On examining the grating we also find that the phenomena seen in each of the beams are the same as in the extraordinary ray of calcite. There are two focal points for the two systems of lines, but only at particular azimuths, and they disappear on being rotated to other azimuths. In the line of the axis there is thus no *ordinary ray*, and this explains what at first surprised me very much—why at certain azimuths it is impossible to see any trace of lines through a perfectly transparent substance, through which, with the naked eye, distinct objects are well seen in all positions. On careful examination it is found that the two extraordinary rays are very nearly equal, and differ chiefly in being in opposite planes. The result is that, when combined together, or when no nicol is used, both systems of lines are visible at so nearly the same focus, that they look very much like the two different unifocal images seen in a section of calcite cut perpendicular to the axis. That they are not so is, however, at once seen on rotating the lines, or on placing the nicol over the eye-piece.

The apparent indices of refraction were found to be approximately as follows :—

	Polarized in one plane.	Polarized in the opposite plane.
For one set of lines	1·676 ...	1·388
For the other set of lines ...	1·384 ...	1·677

According to Professor Stokes's theoretical deductions, assuming the three principal true indices to be as first given, these numbers should be respectively,

1·684 ... 1·388
1·392 ... 1·689

Considering the many sources of error, and that the specimen is certainly a mixture of crystals at different azimuths, the agreement is as close as could be expected, and at all events sufficient to show that the general principles of both theory and observation are correct.

2. *Section cut somewhat obliquely to the principal axis.*—This section shows the same general facts as that just described, but the two images

are much less symmetrical. The indices were found to be approximately as follows:—

	Polarized in one plane.	Polarized in the opposite plane.
For one set of lines	1·686 ...	1·390
For the other set of lines ...	1·422 ...	1·670

The chief point of interest in this case is that it proves that the actual value of some of the indices may be considerably different, if the direction of the section vary.

3. *Section cut parallel to the principal axis, and perpendicular to the plane of the twin-plates.*—The section was cut in this direction in order to avoid as much as possible the disturbing effect of the visible twins. The two rays, polarized in opposite planes, are both very decidedly bifocal, and the apparent indices were found to be approximately as follows:—

	Polarized in the plane of axis.	Polarized perpendicular to axis.
For lines parallel to axis ...	1·649 ...	1·521
For lines perpendicular to axis ...	1·684 ...	1·852

We here see very nearly the same abnormal increase of one of the indices, as in the case of calcite. Those having the values 1·521 and 1·684 closely approximate to two of the true indices.

4. *Section cut in the plane of one of the faces of the six-sided prism, parallel to the axis, but inclined at about* 60° *to the plane of the twinning.*—This section really gives the combined effects of crystals in somewhat different positions, though they are all combined together as twins in one particular plane. Its chief interest is that one image is so nearly unifocal that, without stopping off half the object-glass, by means of the cap previously described, it can scarcely be distinguished from an ordinary ray, with which it also agrees in being polarized in the plane of the axis. It is important to bear this fact in mind, since, if a crystal were inadequately examined only in such a direction, it might be thought to have only one axis of double refraction, when it really had two, as would be at once apparent if it were possible to examine the specimen in some other appropriate direction. These observed facts agree with what Professor Stokes has deduced theoretically. The apparent indices were found to be approximately as follows:—

	Polarized in the plane of axis.	Polarized perpendicular to axis.
For lines parallel to axis ...	1·664 ...	1·521
For lines perpendicular to axis ...	1·664 ...	1·795

One of these indices perhaps represents a real one. The rest are certainly only apparent.

It will thus be seen that the phenomena presented by crystals having two axes of double refraction are very complicated. Usually there are four different apparent indices; and though, according to the direction of the section, one or two of these may closely correspond with two of the three real indices, it would often require much care to distinguish the real from the apparent, especially if the true direction of the axes of the crystal were unknown. The existence of two axes of double refraction could, however, generally be proved by the two bifocal images.

Other Crystals having two Axes of Double Refraction.

Nitre. My sections, cut perpendicular to the axis, were made for a different purpose, and at the two focal points the lines at right angles to each other are only just sufficiently separated to prove that there are two axes of double refraction. I mention this merely as an example of what occurs in a biaxial crystal which differs but little from a uniaxial.

Barytes. This mineral is in some respects very suitable for examination, being easily procured, transparent, and free from irregularities. It can also be easily cut and polished. The only objection is that the difference in the indices is small. According to Heusser they are for the central red 1·645, 1·635, and 1·634. In the case of a section cut perpendicular to the principal cleavage, in a plane bisecting the acute angle formed by the two secondary planes of cleavage, which is in fact a section in the plane of two of the axes of the crystal, the apparent indices of refraction were found to be as follows:—

	Polarized parallel to the chief cleavage.	Polarized in the opposite plane.
For lines parallel to the cleavage ...	1·635 ...	1·648
For lines perpendicular to the cleavage	1·648 ...	1·630

In the case of a section cut in a plane perpendicular to the above, that is to say, in the plane of two of the axes of the crystal, perpendicular to the chief cleavage and bisecting the obtuse angle of the secondary cleavage, the indices were found to be:—

	Polarized parallel to the chief cleavage.	Polarized in the opposite plane.
For lines parallel to the cleavage ...	1·658 ...	1·633
For lines perpendicular to the cleavage	1·658 ...	1·682

In the case of a section cut parallel to the plane of the chief cleavage, the indices were found to be :—

	Polarized in the plane of the shorter diagonal of secondary cleavage.	Polarized in the plane of the shorter diagonal.
For lines parallel to the shorter diagonal	1·645 ...	1·634
For lines parallel to the longer diagonal	1·645 ...	1·656

In the case of a section cut in the plane of the secondary cleavage, the indices were :—

	Polarized in the plane of the chief cleavage.	Polarized in the opposite plane.
For lines parallel to the chief cleavage	1·636 ...	1·644
For lines perpendicular to the chief cleavage	1·650 ...	1·659

The equality in focal length of two sets of lines, as seen through the section first described, is not in any way an indication of a true or even an apparent unifocal image, since the equal foci were for pencils polarized in opposite planes. In only one out of the four different sections could there be any doubt about the existence of two bifocal images; and, even in that case, the unifocal character of one of the images was at once seen to be only apparent when the semicircular stop was used. Considering that two of the indices differ only by 0·001, it is satisfactory to find that the simple method of examination described in this paper gives such very distinct and positive results.

The apparent unifocal character of one image, in one instance, is, however, a further illustration of the necessity of a careful examination before concluding that any crystal, showing such an image, has only one axis of double refraction.

Mica (*muscovite*). A section in the plane of cleavage, which is perpendicular to the principal axis of the crystal, shows the circular hole as a symmetrical cross at two different foci. One branch is polarized in the line of the axis joining the centres of the coloured rings seen with polarized light, and the other perpendicular to it. This is the line of axis to which I refer below, in giving the indices. If the different branches of the crosses are at different foci, they differ so little that I was unable to recognize the difference, even in an excellent specimen $\frac{1}{5}$th of an inch thick.

	Polarized in the plane of this axis.	Polarized perpendicular to it.
For lines parallel to the above-named axis	1·528 ...	1·598
For lines perpendicular to it ...	1·598 ...	1·528

Orpiment. The double refraction is so powerful that a section in the plane of cleavage only $\frac{1}{20}$th of an inch in thickness shows four distinctly different foci. The circular hole is seen as an unsymmetrical cross at two chief foci, but unlike mica the two sets of arms are not in focus at the same time. The two images polarized in opposite planes are most distinctly bifocal, and give the following approximate indices, two of which are probably true, and the others only apparent:—

	Plane of polarization parallel to one axis.	Plane of polarization parallel to the other.
For lines parallel to one axis ...	2·09 ...	3·03
For lines parallel to the other axis	2·68 ...	1·81

Peridot. My section is cut parallel to one of the principal axes, but the specimen does not show sufficiently well the direction of the other axis. Two widely separated images of the circular hole are seen, both of which have the characters of extraordinary rays. The apparent indices were found to be:—

	Polarized in the plane of the axis.	Polarized in the opposite plane.
For lines parallel to the axis ...	1·654 ...	1·679
For lines perpendicular to it ...	1·728 ...	1·616

These all differ so much that there can be no doubt of the existence of two bifocal images, and that the mineral has two axes of double refraction.

Topaz. A section cut perpendicular to the principal axis shows the circular hole at two different levels, but neither is sensibly distorted. The apparent indices of refraction were found to be approximately as follows:—

	Polarized in the plane of the shorter axis.	Polarized in the opposite plane.
For lines parallel to shorter secondary axis	1·621 ...	1·606
For lines parallel to the longer secondary axis	1·636 ...	1·649

A section cut perpendicular to the principal axis, but doubtfully placed with reference to the other axes, gave the following indices:—

	Polarized in the plane of the principal axis.		Polarized in the opposite plane.
For lines parallel to the principal axis	1·618	...	1·635
For lines perpendicular to this axis	1·639	...	1·638

This case is interesting as showing two nearly equal indices for lines in the same direction, with the light polarized in opposite planes. Both this and the former do, however, clearly show that the method of study now being described enables us easily to prove that there is no true ordinary ray in topaz, although its double refraction is comparatively weak.

Anhydrite. A section cut parallel to the longest of the three axes and to one of the other axes, gave the following approximate indices:—

	Polarized in the plane of the chief axis.		Polarized in the opposite plane.
For lines parallel to the chief axis	1·587	...	1·548
For lines perpendicular to this axis	1·617	...	1·631

In the case of a section cut in the plane of the principal cleavage the apparent indices were:—

	Polarized in the plane of (1).		Polarized in the plane of (2).
For lines parallel to one of the shorter axes (1)	1·593	...	1·654
For lines parallel to the other (2) ...	1·691	...	1·601

The structure of this mineral makes it somewhat difficult to determine the indices with accuracy, and perhaps there ought not to be so many as the eight different values given above. There cannot, however, be any doubt as to the existence of two well-marked bifocal images, and of at all events six different indices, some probably true, and some only apparent.

Selenite. The double refraction of this mineral, when cut parallel to the principal cleavage, is so weak, that a specimen $\frac{3}{10}$ths of an inch thick shows one pair of lines only just at different foci, and the other pair only at one focus. The indices were found to be approximately as follows:—

	Polarized in the plane of (1).		Polarized in the plane of (2).
For lines parallel to one axis (1) ...	1·536	...	1·532
For lines parallel to the other (2) ...	1·527	...	1·532

With the semicircular stop it was just possible to distinctly recognize the bifocal character of even the second image. The chief interest of this mineral is in its showing that such small *relative* differences can be recognized. They correspond to $\frac{1}{1000}$th of an inch or less in focal

length, and there can be no doubt of this, when it is seen in the self-same specimen.

Adularia. I mention this as an example in which the double refraction was so small that I was unable to prove the existence of any true bifocal image with a specimen 0·15 inch thick. It gave merely the one index 1·540. In reference to this fact I may here remark that the method of examination described in this paper shows the difference between the different systems mainly by differences in focal lengths, and, if these should in any case be considerably less than $\frac{1}{1000}$th of an inch, it may not be possible to recognize them. One result of this is that we may not be able easily to separate all minerals into perfectly separate groups, though the facts are no less characteristic of each particular kind.

Clinochlore. This mineral, cut perpendicular to the cleavage, may be given as an example of the effects of very strong dichroism, which is at once apparent when the circular hole is examined; but, if it were not taken into account, an observer might be misled. One image is not much coloured, but the other is so very dark that we may say that light is transmitted polarized only in one plane. Its laminar structure interferes much with the definition of lines seen through it, but some parts were sufficiently solid to give good results. The single image shows the two systems of lines at so nearly the same focus, that, without the semi-circular stop, no difference could be seen with a specimen $\frac{1}{8}$th of an inch in thickness. We thus get only one index of refraction, 1·595, as though the crystal had no double refraction. This is, however, manifestly because the other image is too dark to be visible.

None of the various other minerals which I have been able to examine show any facts differing in general character from those now described, and it therefore appears to me unnecessary to give further details. On the whole the phenomena are so clearly connected with double refraction that I think we may safely connect them with it in the following manner:—

General Relations between the Images and Double Refraction.

1. Crystals having no double refraction have no bifocal image.

2. Crystals having one axis of double refraction have one bifocal image.

3. Crystals having two axes of double refraction have two bifocal images.

4. Other circumstances being the same, the distance between the foci varies directly as the intensity of the double refraction, and directly as the thickness of the specimen.

Exceptions.—The only apparent exceptions to these laws hitherto met with are those dependent on such strong dichroism that only one image can be seen.

Though the inverse of all the above laws is probably true, yet it must be borne in mind that in some cases special means may be necessary in order to distinguish between an apparent and a true unifocal image. It must also be remembered that, since the distance between the foci in a bifocal image varies as the thickness of the mineral, it may not be possible to recognize it, if the specimen be too thin.

Application of the above described methods and conclusions to Practical Mineralogy.

The whole subject having grown up during the last two months, my attention has been so much directed to the establishment of general principles and methods that I have had no time to apply them to the determination of doubtful specimens. It is, however, quite apparent that even independent of accurate measurements, the methods described in this paper enable us to observe a new class of properties, which are most eminently characteristic of each particular mineral. Unlike some of the most important phenomena seen with polarized light, many of these properties can be observed in sections cut in any direction whatever, and in many cases the natural crystals need not be cut at all, comparatively small as well as larger specimens may be used, without previous preparation or permanent injury. This is of course a very great practical advantage. It is only necessary that there should be two opposite sufficiently flat faces, and that in some one part the crystal should be sufficiently transparent over a surface not necessarily more than $\frac{1}{20}$th of an inch square. Perfect freedom from impurities is by no means essential. Many good observations may be made with specimens loaded with fluid-cavities and minute crystals or granules. What is of far greater importance is that the mineral should not have a laminar or fibrous structure, giving rise to optically-discontinuous planes in any one predominating direction, much inclined to the plane of the section, since they produce distorted images of the lines by internal reflections. A very considerable amount of irregularity in the surface of the crystals

may be overcome by the use of oil of cassia, or some other liquid of nearly the same refractive power as the mineral, placed between it and both the thick supporting glass and the thin cover. Results thus obtained might be only approximately true, but yet sufficiently to decide a doubtful question, when it was desirable not to polish the faces artificially. This is, however, in some cases very desirable or even necessary. Irregularities in the surfaces are objectionable in more ways than one, since they not only interfere with definition, but also with the correct measurement of the thickness of the specimen. I must, however, say that some of my best results have been obtained with crystals in their natural state ; and, where their faces are good, they are far better than specimens badly cut and polished. One great advantage in natural crystals is that the planes are in a true crystalline direction, whereas, in cutting a specimen, much care is necessary to avoid errors due to a departure from the true plane. The opposite surfaces ought to be flat and parallel, but a slight inclination does not produce any appreciable error. On the whole it is far better to mount the specimen on glass, and cover it with a thin glass, cementing with Canada-balsam, since this greatly reduces the effects of irregularities.

Many very valuable facts may, however, be learned from a specimen cut in an unknown direction. It may show, not only whether the crystal has or has not double refraction, but also whether it has one or two axes. When there is no double refraction, or only one axis, the index of refraction of the ordinary ray can always be determined, and may assist in the identification of the mineral ; or if there be no doubt about this, a difference in the index may point out some important variation in the chemical composition. By using the round hole and the grating the direction of the section may be approximately determined, and also the general character of the double refraction, whether strong or weak, positive or negative. In the case of crystals having two axes of double refraction, the results are necessarily more complicated ; but, even when the direction of the section is unknown, many important facts may be observed. If, however, we can examine a natural or artificial specimen from $\frac{1}{10}$th to $\frac{1}{2}$ inch thick, in one or more known directions, the phenomena I have described are so very definite and characteristic that they appear to me likely to be of very considerable use in the identification of minerals.

The facts described in this paper also have an important bearing on the study of the microscopical structure of rocks. Only an ordinary ray, or an extraordinary ray differing so little from an ordinary as to be

almost unifocal, could give perfect definition of cavities or enclosed crystals, seen through a relatively considerable thickness of any mineral having a powerful double refraction. It is therefore necessary not only to get rid of one of the two images by using polarized light, but so to arrange the plane of polarization as to make use of the ordinary ray, or of that extraordinary ray which is the most nearly unifocal. The importance of this does not depend merely on the absolute thickness of the mineral, but also on the magnifying power employed, since the distortion of minute objects, seen with high powers through a small thickness, would be as great as that of larger objects seen with a lower power through a greater thickness, and might give rise to very false appearances. Though in most minerals this source of error may be disregarded, yet at the same time it must be borne in mind that cases might occur in which it would be impossible to see a small object, well defined, by any means hitherto adopted.

Fig. 1. 2. 3. 4 *a*. 4 *b*.

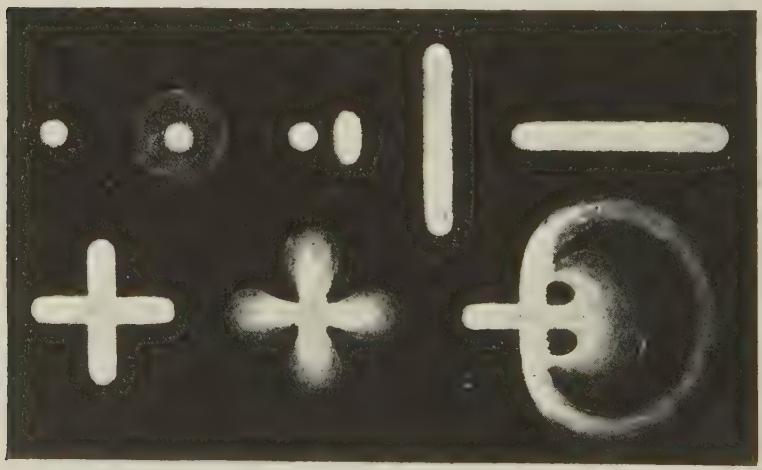

Fig. 5. 6. 7.

Description of the Figures.

The subjoined explanations will be better understood after reading the more full account of the various special examples, but it appears desirable to give some description of the different figures.

Fig. 1 is the simple hole as seen through a mineral having no double refraction (p. 196).

Fig. 2 shows one of the images seen in a section of calcite cut perpendicular to the axis, surrounded with the larger nebulous circle, due to the other image being much out of focus (p. 197).

Fig. 3 is what is seen where a section of one uniaxial crystal is cut obliquely to the axis. The ordinary image is circular, and remains in the centre, whilst the extraordinary is somewhat distorted, and, by inversion, as it were, raised in the line of the axis. The fig. represents the effect of a thin slice of a mineral in which the double refraction is powerful, or of a thick slice of one in which it is weak (p. 199).

Fig. 4 shows at *a* and *b* the two very much elongated images of the circle, seen by means of the extraordinary ray, through a section of calcite cut parallel to the axis. These two images are at two different, widely-separated foci. If both could be seen at the same time, they would form a cross similar to fig. 5. (p. 200).

Fig. 5 represents one of the two crosses, seen at two widely-separated foci, in looking through a section of such biaxial crystals as aragonite or mica, cut perpendicular to the vertical axis. The circular hole is drawn out in two directions, at right angles to each other, parallel to the axes of the crystal, into two beams polarized in opposite planes (p. 204). The irregularities in the structure of aragonite often cause the arms of these crosses to end in irregular brushes.

Fig. 6.[1] Section of aragonite cut perpendicular to the vertical axis. The spreading out of the ends of the arms of the cross is here apparently due to the crystal consisting of portions having their axes nearly but not absolutely parallel.

Fig. 7.[1] Section of aragonite cut somewhat obliquely to the vertical axis. Here one bar of the cross is distorted into an irregular arc, and one arm of the other bar is spread out into a sort of crescent.

[1] Dr. Sorby's MS. contains no explanation of figs. 6 and 7; those now given being taken from Min. Mag., 1877, vol. i, p. 200. All the above figures were first given in Plate VII of that volume, and they are reproduced here for convenience of reference.

Communications from the Oxford Mineralogical Laboratory. No. XIV.

On the identity of Poonahlite with Mesolite.

By H. L. Bowman, M.A., D.Sc.
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[Read January 26, 1909.]

Introductory and Historical.

AMONG the zeolite specimens from the neighbourhood of Bombay in the Oxford University Collection are several of the well-known type, showing pale green crystals of apophyllite associated with white stilbite and white silky needles labelled as 'poonahlite', on a matrix of purplish-brown amygdaloid, with a layer of a bluish-green, earthy mineral lining the amygdules and underlying the zeolites.

The name poonahlite was originally given by H. J. Brooke,[1] in 1831, to a mineral occurring on specimens which he had received from Henry Heuland. He states that the poonahlite formed slender crystals accompanying apophyllite from Poonah, and was at first taken for mesotype or needlestone, but that it had a prism-angle of 92° 20′. He mentions also that the crystals traversed the mass of the apophyllite and matrix, and among several hundred crystals which he had examined, he had not observed one with a natural termination.

This description so exactly fits the specimens at Oxford that there can be little doubt that these represent the material described by Brooke; and the matter is placed beyond question by the fact that a similar specimen in the British Museum was bought as poonahlite at a Heuland sale in the very same year in which Brooke's description was published.

The only point on which there appears to be a discrepancy is the angle of the prism, which is given by Brooke as 92° 20′, while the

[1] H. J. Brooke, Phil. Mag., 1831, ser. 2, vol. x, p. 110. A. Dufrénoy ('Traité de Minéralogie,' 1847, vol. iii, p. 428) wrongly attributes the name to Gmelin, who, however (Ann. Phys. Chem. (Poggendorff), 1840, vol. xlix, p. 538), speaks of it as having been given by Brooke.

Oxford crystals have angles lying within a few minutes of 91° 29′, as stated below. That there is no great variation in the angles of crystals on different specimens is indicated by the fact that a crystal from a specimen in the British Museum has angles of 91° 20′ and 91° 32′, while one which Mr. A. Hutchinson has kindly sent me from Cambridge has 91° 29′.[1]

Since Brooke's time, material described as 'poonahlite' has been variously identified by different writers with scolecite and with mesolite.

Gmelin,[2] in 1840, gave an analysis of 'poonahlite' from Poonah, associated with apophyllite and apparently similar to that named by Brooke, which showed only 0·66 % of soda, but an excess of about 4 % of alumina at the expense of lime as compared with scolecite of the formula $CaAl_2Si_3O_{10} \cdot 3H_2O$.

Kenngott[3] described yellowish-white and translucent, to colourless and transparent, crystals with a prism-angle of 91° 49′, associated with apophyllite from Poonah, and identified them with antrimolite, i. e. with mesolite, to which this name had been given by Thomson in 1836. His material was not analysed, and he merely quoted Gmelin's numbers as having settled the composition of poonahlite. Apart from the yellowish colour, Kenngott's crystals appear to have agreed closely in character and association with those described below, except that small, greyish-white, spherical groups of herschelite[4] [= chabazite] are mentioned, along with the apophyllite and stilbite.

Petersen[5] analysed some 'vitreous to silky, white to colourless, thin crystal-bundles and prismatic aggregates' sometimes over an inch long, of a zeolite from Poonah, occurring in a melaphyre-amygdaloid with apophyllite. His analysis showed this 'so-called poonahlite' to be scolecite.

In 1881, Luedecke[6] examined crystals 'from Kandallah' and found

[1] In addition to the direct reflections from the faces, the transparent crystals also yield on the goniometer very distinct images by internal reflection at the back faces, and it is possible that these may have led to some confusion in Brooke's measurements.

[2] C. G. Gmelin, Ann. Phys. Chem. (Poggendorff), 1840, vol. xlix, p. 538.

[3] G. A. Kenngott, Sitz.-Ber. k. Akad. Wiss. Wien, 1850, vol. v, p. 237; Kenngott's Uebers. mineralog. Forschung, for 1850-1, 1853, p. 82; Haidinger's Ber., 1851, vol. vii, p. 189.

[4] Some of the Oxford specimens show small globules, which, however, are probably gyrolite.

[5] T. Petersen, Neues Jahrb. Min., 1873, p. 852.

[6] O. Luedecke, Neues Jahrb. Min., 1881, vol. ii, p. 14.

them to be scolecite. This seems to have been taken by Hintze[1] as proving poonahlite to be scolecite and not mesolite; but there is nothing to show that Luedecke's material was similar to Brooke's.[2]

An analysis, quoted by Hintze, of scolecite 'from the East Indies' by W. J. Taylor,[3] clearly refers to a different occurrence, as the author speaks of 'globular masses, of a radiated structure, 5 to 6 inches in diameter'.

An analysis by Collier, published in the fifth edition of Dana's 'System of Mineralogy' (1868, p. 429), of a zeolite from 'the Ghauts' having the composition of scolecite, may possibly also refer to another mineral.

Occurrence and Associations of Poonahlite.

Some time ago, certain brilliant, colourless prisms, occurring on one of the Oxford specimens (Reg. No. 1339) and similar to the silky needles in size and habit, attracted my attention as being excellently suited for optical examination.

The microscope showed at once that they could not be scolecite, as the plane of the optic axes was found to be transverse to the prism. On the other hand, the optical characters did not appear to agree with those of mesolite; which, however, were at that time but very imperfectly known.[4] It thus became necessary to determine the composition of the crystals, and an analysis was made, of which the results are given in the table below.

The specimen above referred to consists of white, sheafy stilbite crystals (2 cm. diameter) with pale green crystals of apophyllite, of 7 mm. diameter, showing the forms $a\{100\}$, $c\{001\}$, $p\{111\}$, as well as masses of small, colourless crystals of the same form and about 1 mm. diameter. The poonahlite forms brilliant, square, transparent prisms, up to $2\frac{1}{2}$ cm. long and 1 mm. in diameter, which are partly or entirely embedded in the apophyllite and stilbite. In addition to these there are also some silky-white, radiating groups (2 cm. radius) of more or less perfectly crystallized prisms, which are identical in their optical properties with the transparent crystals. The groups are sometimes

[1] C. Hintze, 'Handbuch der Mineralogie,' 1897, vol. ii, p. 1704.

[2] The well-known magnificent specimens of stilbite, apophyllite, scolecite, and other zeolites from Poonah, were obtained during the construction of the Great Indian Peninsula Railway. This, however, was not made till 1851, i. e. long after the description of poonahlite by Brooke.

[3] See F. A. Genth, Amer. Journ. Sci., 1854, ser. 2, vol. xviii, p. 410.

[4] Compare C. Hintze, 'Handbuch der Mineralogie,' 1897, vol. ii, p. 1706.

compact, like some varieties of natrolite, but commonly consist of well-defined square prisms (often almost perfectly transparent) lying loosely among white, cottony fibres. The transparency of the prisms usually increases from the centre towards the periphery of a group, and the silky appearance is due to the inclusion of some of the fibres in parallel position. Examination of the fibres in oil under the microscope shows that, though they are exceedingly fine, their optical properties are probably the same as those of the prisms of poonahlite. No attempt has been made to separate them from the silky crystals, which were merely cleaned by rolling between the fingers.

Chemical Composition.

The whole of the material used for analysis was obtained from this specimen. It was very carefully purified (an easy matter, owing to the perfect prismatic cleavage), and the whole of it was passed under the microscope between crossed nicols and ascertained to be free from all traces of apophyllite and stilbite.

A preliminary qualitative examination of some of the silky crystals showed the presence of alumina, lime, and soda, and the absence of magnesia.

Preliminary experiments showed, further, that drying the powder in a water-oven at 97°–100° C. caused but a very slight loss of weight, quite sufficiently accounted for by an increase, due to absorption of moisture, which had been observed on grinding the crystals. A low red-heat was found to be required for the complete expulsion of the water, and no further loss was caused by ignition at bright redness.

The ignited powder, even when not sintered, dissolved with extreme slowness in hydrochloric acid; and it was, therefore, necessary to use separate portions for the estimation of the water and the other constituents. Three determinations were made, using respectively transparent prisms only, silky prisms only, and some of a mixture of both kinds which was used for the main determination of the silica and bases. The results are given in columns I, II, and III. Considering the small quantities used, the slight differences found can hardly be taken to indicate an actual difference in composition between the silky and transparent crystals.

Two determinations of the silica and bases were made with the mixture of silky and transparent material; and the results are given in columns IV and V. The method of analysis was the same in both cases. The powder, dried at 97°–100°, was dissolved (without difficulty) in

hydrochloric acid, giving a gelatinous mass; and the silica was determined, after a double evaporation, by the loss of weight of the ignited residue caused by fuming with hydrofluoric acid.

In the filtrate from the silica, after removal of most of the acid by evaporation, the alumina and lime were precipitated together, boiling, with ammonia and ammonium carbonate. The precipitate was redissolved in hydrochloric acid, the solution heated to expel carbonic acid, and the alumina separated by hot precipitation with ammonia. The precipitate of alumina was washed with ammonium nitrate solution, and in the case of no. V reprecipitated after solution in nitric acid to remove suspected traces of lime. The lime was estimated in the filtrate by precipitation with ammonium oxalate, and conversion into carbonate.

In the filtrate from the lime and alumina, the total alkalis were estimated as chlorides, after expulsion of the ammonium chloride. A trace of potash was then precipitated with platinum chloride, and the soda obtained by difference.

	I.	II.	III.	IV.	V.	Mean.	Mesolite.
Weight of substance.	0·0959	0·0878	0·0581	0·2451	0·2494	—	
SiO_2	—	—	—	46·92	46·51	46·71	46·5
Al_2O_3	—	—	—	26·36	26·54	26·45	26·2
CaO	—	—	—	9·31	9·40	9·35	9·6
Na_2O	—	—	—	5·33	5·32	5·33	5·3
K_2O	—	—	—	0·11	0·11	0·11	—
H_2O	12·72	12·41	12·56	—	—	12·56	12·4
Total	—	—	—	—	—	100·51	100·0

The presence of 5 % of soda shows that the present crystals must be referred to mesolite. Their composition, like that of much typical mesolite, agrees indeed with that of a double salt of one molecule of natrolite with two of scolecite, i. e.

$$(Na_2Al_2Si_3O_{10} \cdot 2H_2O) \cdot 2\,(CaAl_2Si_3O_{10} \cdot 3H_2O),$$

which is given for comparison in the last column of the table.

The optical characters also, given below, agree well with those of mesolite from the Færoes, of which a description has quite recently been given by R. Görgey,[1] who accepts the formula mentioned.

[1] R. Görgey, Min. Petr. Mitt. (Tschermak), 1908, vol. xxvii, pp. 255–256.

Geometrical and Physical Properties.

In no case have end-faces been observed, but the crystals admit of a very exact determination of the prism-angle, *mm*. Eleven measurements of this angle, made on six selected crystals giving only first-class reflections, gave values varying between 88° 28′ and 88° 32′, the mean being 88° 30′ 49″. No other forms than *m* appear to be present.

There is an exceedingly perfect cleavage parallel to the faces of the prism *m*; and the crystals commonly break across about at right angles to their length, but the cleavage (if there be one) in this direction is not sufficiently good to yield a reflecting plane.

The density of three small transparent prisms, determined by means of methylene iodide and a Westphal balance, was found to lie between 2·264 and 2·272.

The appearance of the transparent poonahlite crystals under the microscope between crossed nicols is very striking and characteristic, as they show through a pair of prism-faces brilliant blue or brownish-yellow colours, which are often visible side by side in patches or in more or less regular longitudinal stripes, and are independent of the thickness of the crystal. The colours disappear when the crystal lies parallel to one of the principal planes of the nicols. Some few crystals appear almost isotropic.

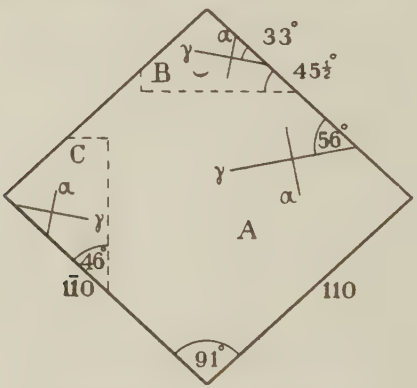
Examination in convergent light shows that the colours are due to the emergence of an optic axis with strong axial dispersion, nearly perpendicular to each of the prism-faces. The axial bar is usually well defined and coloured strongly blue and yellow on its two edges, but occasionally it appears blurred. The inclination of the axis varies slightly, the blue edge of the bar being central in the blue areas, and the yellow edge in the yellow areas. The transverse section described below indicates that this variation is caused by twinning. The blurring of the axial bar, as well as the isotropic character of some of the crystals, is probably also due to twinning.

The plane of the optic axes is thus transverse to the prism, and the axial angle (2V) approximately 90°.

A section of a crystal ground parallel to a plane truncating the acute edge of the prism showed a longitudinal junction, indicative of twinning, and the two portions gave extinction angles of 3° and 3½° on either side of the junction in sodium-light. Convergent light showed a central positive bisectrix, with ill-defined axial brushes just visible at the edge of the field. The whole of the field was coloured blue except the small areas outside the brushes, which were yellow.

A section truncating the obtuse prism-edge showed a very similar appearance, with traces of a longitudinal division into two parts having their extinction-directions inclined to one another at a small angle (2°–3°). Convergent light here showed a normally emergent, negative bisectrix of wide axial angle.

A third section, of 0·6 mm. thickness, ground at right angles to the faces of a stout prism, showed the appearance indicated in the figure. The main area, *A*, showed a definite sharp extinction at about 56° to one pair of edges of the section, and 33° to the other. The two small areas, *B* and *C*, have their directions of vibration parallel, but inclined at 33°



Poonahlite. Transverse section.

and 56° to the same two pairs of edges respectively. All the areas are compensated by a quartz-wedge inserted (approximately) along the shorter diagonal of the prism. Thus, the directions of vibration of *A* and of *B* and *C* are symmetrical about either of the diagonals of the prism. Since the plane of the optic axes is nearly at right angles to the prism, these vibrations will correspond very nearly to the indices α and γ.[1]

The optical characters of the sections prove that the crystals must belong to the anorthic system, with twinning about one or both of the vertical pinacoids.

The optic axial angle was determined for sodium-light, using a natural prism. The apparent angle in air, at 20° C., is 76¼° about the longer

[1] The optic axes of the two parts of the twin will not be parallel, and a comparison of this section with the blue and yellow stripes visible through its side-faces shows that this is the cause of the patches of colour characteristic of the prism-faces.

diagonal of the prism; whence the value of $2V = 81\frac{1}{2}°$. The double refraction is therefore positive. It is very weak, and no trace of rings is ever seen in the interference-figure. The dispersion about the positive bisectrix is $\rho < v$.

The optic axial angle is very sensitive to changes of temperature, so that a change of colour (or, in convergent light, a displacement of the axial bar) becomes visible on merely warming a crystal gently on a slide. The angle about the positive bisectrix increases with the temperature.

Refractive indices, approximating to α and γ, and (still more closely) to β, were determined by means of two prisms, ground so that their refracting angles were bisected respectively by the macro- and brachy-pinacoids. The first of these had an angle of 57° 34′ and gave the following values for sodium-light:—

$$\beta = 1{\cdot}5046 \quad \gamma = 1{\cdot}5048.$$

The other had an angle of 58° 27′ and gave the values:—

$$\beta = 1{\cdot}5046 \quad \alpha = 1{\cdot}5044.$$

Conclusion.

It follows from their chemical composition that crystals apparently identical with those described by Brooke as poonahlite must be referred to mesolite. Their optical properties agree well with those of mesolite from the Færoes, and indicate anorthic symmetry. There is no variation in the prism-angle or in the optical characters of the specimens examined, which would point to a variation in chemical composition, and the analyses given by Gmelin and Petersen remain without explanation.

Communications from the Oxford Mineralogical Laboratory. No. XV.

Note on the spontaneous crystallization of drops of solutions as spherulites.

By Jacques Chevalier.

[Communicated by Principal Miers, and read January 26, 1909.]

PREVIOUS experiments made by myself in the Oxford Mineralogical Laboratory on the crystallization of potash-alum [1] had shown that a drop of supersaturated solution of potash-alum, when left by itself, crystallized almost invariably in birefringent sphero-crystals, which represent a more soluble and less hydrated variety of that substance. It was further suggested (1) that the *spontaneous* crystallization of that particular substance always takes place as spherulites; and (2) that this spherulitic growth is indicative of a sudden change in the solution, which is passing from the metastable state for ordinary alum (in which ordinary octahedra, when introduced, grow by themselves) to the labile state (in which the alum crystallizes as a rectangular network of needles).

The present investigation was undertaken with the object of ascertaining whether growth as spherulites is characteristic of the labile state. The substances experimented upon were selected from those given by Lehmann [2] and by McMahon.[3] The experiments were carried on in the simplest way possible, by taking with a glass rod a drop of a strongly supersaturated solution (of unknown concentration), which was kept slightly warm in a test-tube, and examining it under the polarizing microscope. The temperature of the room was from 19° to 20° C.

The following is a brief summary of the salient features of the most suggestive experiments:—

1. *Lithium sulphate.*

(*a*) A drop taken from a supersaturated solution kept at 54° C. yields after a while a crown of hexagonal plates, with uniform extinction, growing from the edges towards the centre of the drop.

[1] J. Chevalier, 'On the crystallization of potash-alum.' Min. Mag., 1906, vol. xiv, pp. 134–142.

[2] O. Lehmann, 'Molekularphysik,' 1888, vol. i, p. 388.

[3] C. A. McMahon, Min. Mag., 1893, vol. x, p. 229.

(*b*) A smaller and warmer drop, taken from the solution at about 70° C., crystallizes at once as spherulites, especially along a line of scratch. Some thin plates with a very weak double refraction develop from these.

2. *Ammonium sulphate* drops could not be made to crystallize as spherulites, but generally yielded large orthorhombic crystals, surrounded by rough, grey material. If the drop be heated with the apparatus employed by Professor Miers and Miss Isaac,[1] it crystallizes spontaneously as long needles which branch and grow very rapidly; these appear to belong to the same modification as the plates.

3. *Manganese-potassium sulphate.* Two very small drops were taken from a solution at the temperature of the room, with large crystals growing at the bottom of the tube.

(*a*) In one of them a few strongly birefringent crystals grew from the beginning; the drop became finally divided into several portions, each containing a crystal with some amorphous, slightly coloured material around it.

(*b*) In the other, which was kept free from crystals, nothing appeared. Twenty minutes later, the drop being scratched with a pin, spherulites appeared along the lines of scratch, and then suddenly spread over the drop in concentric rings, from which, after a while, birefringent plates began to grow.

4. *Lithium phosphate.* A drop of sodium phosphate was mixed with a drop of lithium sulphate. A few minutes after, spherulites of lithium phosphate were generally found growing on the edges of the drop, with a few grey, birefringent plates. The drop, being slightly warmed and then scratched, solidified suddenly in concentric rings of spherulites and needles. When the crystallized drop was breathed upon, or some water added to it, the spherulites remained unchanged, and the plates dissolved away, or sometimes recrystallized as spherulites.

5. *Iron-sodium sulphate* (9·48 grams of Na_2SO_4 with 10·13 grams of $FeSO_4$). If a drop of the solution is kept free from crystals, after a while spherulites, or sometimes sphero-crystals (i. e. crystals grouped in the exact form of a spherulite), appear in different parts of the drop.

(*a*) If the drop is then scratched as soon as the sphero-crystals have made their appearance, nothing happens; but if it is inoculated with a particle of the substance, a radiating network of beautiful needles spreads at once over the drop, with plates growing on them, or from them.

[1] H. A. Miers and F. Isaac, Journ. Chem. Soc., 1908, vol. xciii, p. 928.

(*b*) It was further found that scratching parts of those drops, in which the network and the plates had not been growing, but which had been allowed to evaporate further, made the plates appear along the lines of scratch. The experiment was repeated with large drops, spread in a uniformly thin layer, after spherulites (or sphero-crystals) had been left growing for ten or fifteen minutes: care was taken to scratch without touching any of the spherulites; it was then found that mere scratching induced the network to start.

(*c*) If a fresh drop of solution is inoculated at once, before the appearance of spherulites, it yields a few flat rhombic (or sometimes triangular) crystals growing individually. But generally, after ten or fifteen minutes, perfect spherulites and radiating plates make their appearance.

The angle made by the plates with the axes of the network from which they were growing was always about 116°. The extinction in the plates was inclined at 29° to the principal axis; in the flat rhombic crystals at 21°. A few of these rhombic crystals were carefully examined and found to be positive and biaxial.

The two most interesting substances, besides iron-sodium sulphate, as regards spherulitic growth, were found to be potash-alum and lithium-sodium sulphate.

6. *Potash-alum.* The experiments made on this substance having invariably corroborated those described in the previous paper need not be described at length.

A drop of supersaturated solution of potash-alum always crystallizes as spherulites, except when octahedra have been growing in it from the beginning (that is, are already in the solution). So that the spontaneous crystallization of a strongly supersaturated (assumed to be labile) solution of potash-alum in drops is always spherulitic. If octahedra have been introduced, they continue to grow by themselves, until spherulites appear, when the network often starts from the extremity of a quickly growing octahedron, and spreads thence over the whole drop.

A spherulite introduced into a supersaturated (but metastable) drop yields octahedra.

It is conceivable that the behaviour of the thin drops examined under the microscope is peculiarly characteristic of thin films.

In order to ascertain whether still thinner layers of solution behave in the same way, some experiments were made on extremely thin films of potash-alum solution suspended in a ring of platinum wire. The films were watched for a long time, but yielded nothing, and finally they broke up. Others, inoculated with potash-alum, yielded octahedra. They could

not be made to crystallize spontaneously, and there is no evidence that they pass into the labile state.

7. *Lithium-sodium sulphate.* The solution was obtained by mixing solutions of lithium sulphate and sodium sulphate in the proportion of 3 grams to 3·9 grams respectively.

It was found that drops of lithium-sodium sulphate solution always crystallized spontaneously as spherulites, together with blade-shaped crystals. Both modifications always appear side by side, but it is difficult to say which appears first: generally, with drops taken from the solution at about 35–45° C., spherulites appeared first, and then blades developed from them; with drops taken from the same solution at about 60–70° C. (which therefore cooled very quickly on the slide to the temperature of the room) blades were first visible, and soon after, under every blade or nucleus from which blades were growing, a well-formed spherulite could be seen.

Some experiments made on this substance deserve to be described in detail:—

(*a*) A very thin drop of lithium-sodium sulphate having been slightly warmed, and then (inadvertently) placed rather abruptly on the stage, crystallized at once, all round the edges, as spherulites, and spherulites only. Scratching the middle part of the drop, without touching any of the spherulites, caused a number of spherulites to appear all along the lines of scratch.

(*b*) Two very small drops, free from crystals and taken from the solution at about 65° C., were placed side by side on the glass slide, and joined by a small channel of solution; blades were seen growing on the edges of one of them, while the other remained uncrystallized; the latter being then scratched with a clean pin, spherulites appeared on the lines of scratch, and from them some birefringent blades, with straight extinction, and terminated by two edges making an angle of 117°. This experiment was frequently repeated with the same result. In one experiment scratching a drop in which a few crystals had been growing from the beginning on the edges produced—

(1) no effect,

(2) a cloud of minute spherulites,

(3) later, blades without spherulites,

(4) finally, some small hexagonal crystals, which soon began to dissolve again.

In another experiment a metastable drop, which on scratching yielded nothing, was slightly warmed so as to increase its concentration by

evaporation; spherulites then appeared along the lines of the original scratches, and after a while continued to grow as hexagonal crystals.

(*c*) The solution having been kept for two hours in a hot bath, and a drop taken at 76° C., blades appeared at once all round the edges, and then spherulites developing in groups, under the plates, and nearer the middle of the drop. The drop was then warmed, when it crystallized at once in concentric rings of spherulites, with some amorphous material among them, and blades in the centre.

(*d*) Another drop taken from the same solution at the same temperature yielded one blade growing on one edge of the drop. The drop being then scratched, a number of spherulites appeared, from which blades grew. After a while some of the spherulites became transformed into small crystals, of a very regular hexagonal shape, similar to those figured by Rammelsberg.[1] Then some long blades grew towards the centre of the drop, together with spherulites, most of which had the shape of regular hexagons.

(*e*) *Inoculation of various drops with spherulites* :—

(1) A spherulite being introduced into the middle of a fresh drop—which was probably just saturated—dissolved away.

(2) A spherulite introduced into the middle of a drop—which was probably metastable—with a few spherulites and blades growing on its edges, became after a while recrystallized into small hexagonal crystals of the shape described above : scratching then had no effect.

(3) A spherulite being introduced into a drop—which was probably labile—in which spherulites were growing rapidly after the appearance of the blades, and where mere scratching produced a cloud of minute spherulites, continued to grow, and then yielded blades radiating from it in all directions.

In one experiment a few small spherulites were introduced into a drop where a blade was beginning to grow: they remained unchanged ; one of them was put into a thin droplet close by, and started a number of spherulites with blades. The large drop being scratched now yielded nothing. After a while the blades began to grow faster, a few spherulites appeared elsewhere, and those introduced began to grow, blades started from them, together with a few hexagonal crystals; scratching now produced a cloud of crystals.

In these experiments three modifications of lithium-sodium sulphate were observed:—

(1) The small *hexagonal crystals* of a perfect shape, agreeing in every

[1] C. F. Rammelsberg, 'Kryst.-Phys. Chemie,' 1888, Abth. i. p. 408.

respect with the description given by Rammelsberg (loc. cit., p. 408); their refractive index is less than that of the other modifications.

(2) The long *blade-shaped crystals.* These seem to be orthorhombic with a terminal angle of about 120°. It was very easy to examine some of them. They almost invariably lie on one large face, which is perpendicular to the acute bisectrix, and are elongated along one edge, which is parallel to the plane of the optic axes. They have straight extinction, and are biaxial and negative.

(3) The *spherulites.*

Experiments have shown that the hexagonal crystals always grow individually, by themselves and quietly (metastable growth), but that the blades and spherulites, which generally appear together, grow very quickly and in different portions of the drop at the same time (labile growth). When hexagonal crystals appeared in the drop after spherulites and blades had been growing, we may confidently assume that the drop had been reduced to the metastable stage.

Conclusions.—It is very difficult to draw any definite general conclusions from the above experiments. The spontaneous crystallization even of those substances which may yield spherulites takes place in some as spherulites (lithium sulphate, lithium phosphate), in others as ordinary crystals (ammonium sulphate), in others again (lithium-sodium sulphate) sometimes as spherulites and sometimes as ordinary crystals, or as both. Potash-alum is the only substance which always crystallized spontaneously in spherulites.

Again, spherulitic growth is best shown by hydrated compounds, which may yield different hydrates, and it is often difficult to ascertain which of them is present.

Further, with these microscopical observations it is difficult to ascertain the concentration and the temperature.

Nevertheless, it is clear that spherulites and sphero-crystals are characteristic of the spontaneous crystallization of many solutions in thin drops. When other crystals grow first in such solutions, it is probably because they have been introduced; the drop, indeed, in that case always appears to be metastable; for (1) inoculation produces the slow 'metastable growth', (2) scratching or other mechanical influences have no effect. Such is the case, for example, with potash-alum; and again, with a drop of lithium-sodium sulphate, scratching only induces crystallization after spherulites, in addition to the blades, have made their appearance, or when they are just about to appear.

On the other hand, spherulites are undoubtedly characteristic of a quick

growth, in which crystals start and grow very rapidly from a centre or nucleus of crystalline structure (hence the spherical shape). That the spherulites mark the passage of the solution to the labile state is indicated by the following facts :—(1) When spherulites are making their appearance, crystallization may be induced by mere mechanical means. Scratching makes a cloud of crystalline particles appear on the lines of the scratch, either at once (if spherulites are growing), or after a while, when the solution has been reduced to the spherulitic state. (2) When crystals are growing at the same time as spherulites, they assume the elongated shape of blades or needles, or form a regular network of rods, which have been proved to be characteristic of a labile growth. This was noticed in nearly all the foregoing experiments, and is also referred to in the descriptions of 'circular crystals' and of their production by Sir David Brewster.[1] (3) Inoculation of such a drop with a crystalline particle of the substance always produces elongated growth, or a network ; and this appears to be an even more convincing test of the passage to the labile state than crystallization along lines of scratch.

Two very interesting features to be noticed in connexion with these experiments are :—

(1) *The pre-arrangement of drops before passing to the labile state*,[2] which would explain the hexagonal shape of some sphero-crystals. For instance, a small drop of zinc sulphate, which was left to crystallize alone, was found after two hours to have crystallized as a single crystal, with bands radiating regularly from the centre of the drop. The same process took place twice, in the most perfect manner, with potash-alum.

(2) *The rhythmic growth in labile drops*.[3] I have no doubt that there is an alternation—sometimes very quick, sometimes slower, according to the conditions of the drop and the rate of crystallization—of the labile and metastable states in a drop, which is reduced from labile to metastable by a quick crystallization, and then brought back to the labile state by further concentration. Or in parts of the same drop a circular layer may be reduced by quick concentric crystallization to the metastable state, whereas the following one is still labile : this would account for the growth of concentric rings of spherulites and plates, roughly parallel to the edges of the drop, often noticed during these experiments. Hence, also, the appearance of hexagonal crystals in lithium-sodium

[1] Sir David Brewster, Trans. Roy. Soc. Edinburgh, 1853, vol. xx, p. 607.

[2] Cf. my paper on potash-alum, loc. cit., p. 142.

[3] Cf. H. A. Miers, 'Note on the crystallization of potassium bichromate.' Min. Mag., 1908, vol. xv, p. 39.

sulphate solutions, after spherulites and blades had been growing; the spherulites after growing suddenly stop, because they have reduced the drop in their neighbourhood to the metastable condition.

Note. From what has been shown previously, spherulites would appear to be generally [1] a less hydrated modification of the substance; but, contrary to what had been found with potash-alum, they sometimes appear to be more stable and less soluble.[2]

The foregoing experiments were suggested by Professor Miers, and were carried out in the Oxford Mineralogical Laboratory in the summer of 1908.

[1] As with potash-alum, Min. Mag., 1906, vol. xiv, p. 139.

[2] As with sodium sulphate, cf. H. Hartley, B. M. Jones, and G. A. Hutchinson, Journ. Chem. Soc., 1908, vol. xciii, p. 829.

Communications from the Oxford Mineralogical Laboratory. No. XVI.

Contributions to the study of parallel growths of different substances.

By Stefan Kreutz, Ph.D.

[Communicated by Principal Miers, and read January 26, 1909.]

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1. *Parallel Growth on Barytocalcite.*

Mr. T. V. Barker[1] has lately shown that the parallel growth of isostructural substances upon one another is conditioned by similarity of molecular volume. This very important conclusion invites further investigation from this new point of view, and Professor H. A. Miers suggested to me, while working in his laboratory last summer, that I should make experiments on the parallel growth of sodium nitrate on the pseudo-rhombohedral mineral barytocalcite.

The first experiments, which were made on crystals of barytocalcite in the Oxford collection, were unsuccessful, the crystals employed being small and somewhat impure.[2] Later, I received, from the Museum of Practical Geology in London, some very good and perfectly pure crystals of barytocalcite from Blagill, near Alston, in Cumberland. With these crystals I succeeded in obtaining parallel growths of sodium nitrate on all the cleavage-faces—*m* (110) and *c* (001)—just like those of sodium nitrate on calcite.

[1] Mr. Barker's papers are :—

(1) 'Contributions to the theory of isomorphism based on experiments on the regular growth of crystals of one substance on those of another.' Journ. Chem. Soc., 1906, vol. lxxxix, pp. 1120–1158.

(2) 'On the regular growth of soluble salts on each other.' Min. Mag., 1907, vol. xiv, pp. 235–257.

(3) 'The question of a relation between parallel growths of crystals and isomorphous miscibility, and the bearing of parallel growths on questions of isomorphism.' Min. Mag., 1908, vol. xv, pp. 42–53.

See also Zeits. Kryst. Min., 1908, vol. xlv, pp. 1–59.

[2] It is probably the same material which yielded negative results to Mr. Barker.

On the cleavage-face c (001) the rhombohedra of sodium nitrate are so orientated that they extinguish simultaneously with the barytocalcite; and on m (110) the rhombohedral edges of the sodium nitrate are parallel to the prism-edges of the barytocalcite. To obtain this result it is necessary to use very pure crystals and fresh cleavage-faces. The best method is to immerse the cleaved crystal in a warm, saturated solution of sodium nitrate for only a short time, according to the method recommended by Mr. Barker for calcite.

In this way it is possible to obtain on the same crystal of barytocalcite three cleavage-faces covered with microscopic rhombohedra of sodium nitrate in parallel position. The parallel growth seemed to be more perfect and easy to obtain on the faces (110) than on (001), but the difference is not great. If the solution of sodium nitrate is very strong, the regular deposit of crystals forms a crust, as in a zoned crystal. In none of my experiments have the rhombohedra of sodium nitrate been obtained in twinned position (twin-plane (110)), and in this respect barytocalcite differs from calcite.

Barytocalcite is almost isostructural with the rhombohedral sodium nitrate and calcite. There are two perfect cleavages parallel to the prism $m\{110\}$, and that parallel to the base $c\{001\}$ is almost as perfect. On (001) there may sometimes be distinguished a fine striation parallel to the edge [010], like that which is produced on calcite by gliding parallel to (110). This indicates that there is only one glide-plane, viz., that parallel to (100).

The optical properties, and especially the position of the principal directions of vibration, are very similar in both barytocalcite and calcite, as has been shown by Mallard,[1] who called attention to the resemblance between these two minerals.

It is therefore possible to compare the topic parameters of barytocalcite and of sodium nitrate and calcite.[2] For purposes of comparison we can regard the cleavage rhombohedra of calcite and sodium nitrate as rhombic prisms with an oblique basal plane. The topic parameters are then χ, ψ, ω, where $\chi = \psi$, and ω is only different from them in barytocalcite. In the table below, ξ and η are the dimensions of the structural units along the long and short diagonals of the rhombic meshes. In

[1] E. Mallard, 'Sur l'alstonite et le barytocalcite.' (Note posthume.) Bull. Soc. franç. Min., 1895, vol. xviii, pp. 7–12.

[2] W. Haidinger ('Handbuch der Mineralogie,' 1845, p. 279) described the regular intergrowth of crystals of barytocalcite and calcite. See also F. Wallerant, Bull. Soc. franç. Min., 1902, vol. xxv, pp. 183, 210.

barytocalcite the values for the basal and prismatic planes are distinguished as ξ_b and ξ_p respectively. The topic mesh area[1] of the plane (hkl) is denoted by $\Im_{(hkl)}$.

Barytocalcite.	Sodium nitrate.	Calcite.
$\frac{1}{2}$ Mol. Vol. = 41·47	Mol. Vol. = 37·8	Mol. Vol. = 36·8
$a:b:c = 0{\cdot}7717:1:0{\cdot}6254$	$a:b:c = 0{\cdot}79956:1:0{\cdot}64017$	$a:b:c = 0{\cdot}81100:1:0{\cdot}64376$
$\beta = 106°\,8'$	$\beta = 110°\,46'$	$\beta = 109°\,8'$
$\chi = \psi = 3{\cdot}560$ $\omega = 3{\cdot}524$	$\chi = \psi = \omega = 3{\cdot}460$	$\chi = \psi = \omega = 3{\cdot}413$
$\xi_b = 4{\cdot}348,\ \eta_b = 5{\cdot}635$ $\xi_p = 4{\cdot}453,\ \eta_p = 5{\cdot}509$	$\xi = 4{\cdot}322,\ \eta = 5{\cdot}405$	$\xi = 4{\cdot}300,\ \eta = 5{\cdot}302$
$\Im_{(001)} = 12{\cdot}259$ $\Im_{(110)} = 12{\cdot}266$	$\Im_{(100)} = 11{\cdot}679$	$\Im_{(100)} = 11{\cdot}408$
$[1\bar{1}0]\,[\bar{1}\bar{1}0] = \alpha' = 104°\,41'$ $[1\bar{1}0]\,[00\bar{1}] = \alpha'' = 102°\,7'$	$\alpha = 102°\,42\frac{1}{2}'$	$\alpha = 101°\,55'$

The values for χ, ξ, &c., and $\Im$ show a very close agreement. It would perhaps be more correct to double the molecular volume of sodium nitrate, in order to make it comparable with that of barytocalcite (82·94). This agrees with the view of Tschermak, who writes the formula of calcite as $Ca_2C_2O_6$, to make intelligible the isomorphism with dolomite, $CaMgC_2O_6$. The topic parameters would then be: for barytocalcite, $\chi = \psi = 4{\cdot}485$, $\omega = 4{\cdot}440$; for sodium nitrate, $\chi = \psi = \omega = 4{\cdot}319$; and for calcite, $\chi = \psi = \omega = 4{\cdot}301$. These also are very similar.

According to the view of Groth, barytocalcite is a double salt, $BaCO_3$, $CaCO_3$, and this is confirmed by Becker's chemical analyses of the mineral. In agreement with this view is also the constancy of the angles measured on different crystals. I found $mm = 73°\ 9'$ and $mc = 77°\,11'$, whilst Brooke gave the values $mm = 73°\,6'$ and $mc = 77°\,6'$.

The specific gravity of barytocalcite was determined, on about 2·2 grams of material in a pycnometer, as 3·71 at 20° C. If we calculate the specific gravity of an isomorphous mixture of similar composition, containing 57·7 % by volume of witherite and 42·3 % by volume of aragonite, we get 3·696. The value found is a little higher, as is often the case in double salts. Thus, dolomite has a density of 2·87, while the value calculated for an isomorphous mixture is 2·843 (Retgers).

[1] Compare E. Sommerfeldt, 'Physikalische Kristallographie,' 1907, p. 106.

The observed indices of refraction are also higher (except a)[1] than those calculated for an isomorphous mixture of aragonite and witherite. Mallard (loc. cit.) has measured the indices of refraction of witherite, barytocalcite, and alstonite; he found for barytocalcite the values $a = 1{\cdot}525$, $\beta = 1{\cdot}684$, $\gamma = 1{\cdot}686$. On calculating the indices of a mixture as the average of those for aragonite and witherite (the molecular ratio in barytocalcite being 1 : 1), he obtained $a = 1{\cdot}529$, $\beta = 1{\cdot}679$, $\gamma = 1{\cdot}681$. If, however, we take the indices of refraction of a mixed crystal as proportional to the percentages by volume of its components,[2] we get $a = 1{\cdot}529$, $\beta = 1{\cdot}678$, $\gamma = 1{\cdot}681$.

On ignition in a platinum crucible, barytocalcite loses easily 15·4—15·7 % of its weight, and afterwards the loss is very slow. Since the total amount of carbon dioxide theoretically present is 29·6 %, the half that is more readily lost must be combined with the calcium (barium carbonate remaining practically unaltered at a red-heat).

The resistance to solution offered by the faces of the two forms {110} and {001} of barytocalcite is different, as shown by the treatment of a crystal with a dilute solution of citric acid: the face (001) is at once roughened, while the faces (110) remain smooth.

The Meigen reaction for aragonite is also shown very strongly by barytocalcite.

2. *Parallel Growths on Rhodochrosite and Chalybite.*

Mr. Barker has drawn attention to the fact that sodium nitrate gives only irregular deposits on cleavage-surfaces of the rhombohedral carbonates isomorphous with calcite, namely chalybite, rhodochrosite, breunnerite, &c. I have therefore attempted to obtain regular growths of another soluble salt upon these minerals.

The rhombohedral modification of lithium nitrate ($LiNO_3$) is isostructural with calcite, and has nearly the same molecular volume as chalybite and rhodochrosite. But since this modification is unstable at the ordinary temperature (20° C.), experiments with it present some difficulty. A cleavage-fragment of rhodochrosite[3] or of chalybite was suspended by a

[1] This comparison is not altogether satisfactory, and I hope to return to the discussion of the optical properties of barytocalcite and alstonite.

[2] In some cases neither method is exact, according to G. Wulff, Zeits. Kryst. Min., 1907, vol. xlii, p. 558.

[3] Rhodochrosite from the John Reed mine, Alicante, Colorado.

thread in a hot, saturated solution of lithium nitrate, and after removal from the solution it was kept warm; it was thus possible to obtain rhombohedral crystals of lithium nitrate on the surface of the rhodochrosite and chalybite. The edges of the microscopic crystals are almost parallel to the rhombohedral edges of the rhodochrosite or chalybite, like those of sodium nitrate on calcite. These crystals being deliquescent, it is, unfortunately, not possible to preserve them for more than a few minutes, but they may be kept for a longer time in oil or Canada-balsam.

Troost,[1] who obtained the rhombohedral phase of lithium nitrate at 15° C., determined its geometrical properties, and this was also done later by Retgers. The points of equilibrium of the different phases of $LiNO_3 + n$Aq have been determined by Donnan and Burt,[2] who found that above 61·1° C. the stable phase is $LiNO_3$; between 61·1° and 29·6° C., $LiNO_3 + \frac{1}{2}$Aq.; and below 29·6° C., $LiNO_3 + 3$Aq.

The molecular volumes and topic parameters are approximately as follows:—

	Mol. Vol.	χ	$\mathfrak{Z}_{(100)}$	a	$c:a$
Lithium nitrate ($LiNO_3$) ...	29·59	3·181	9·887	102° 16½′	0·843
Rhodochrosite ($MnCO_3$) ...	31·19	3·247	10·275	102 50	0·818
Chalybite ($FeCO_3$)	29·35	3·204	10·000	103 4½	0·819

The values for rhodochrosite are those given by Groth;[3] and the specific gravity (3·949) of pure chalybite is calculated, according to Retgers's rule, from the value (3·937) determined by Hutchinson[4] on analysed Cornish crystals (assuming the specific gravities $CaCO_3$ 2·72, $MnCO_3$ 3·65, and $MgCO_3$ 3·0).

I was unable to obtain a regular growth of lithium nitrate on calcite, although its angles show a closer correspondence than those of rhodochrosite (the rhombohedral angle of lithium nitrate being 105° 40′, and of calcite 105° 5′). An attempt to obtain regular growths of lithium nitrate on fresh cleavage-flakes of mica was also unsuccessful, although the basal plane occurs upon its rhombohedral crystals.

The experiments described above are concordant with the results

[1] L. Troost, Ann. Chim. Phys., 1856, ser. 3, vol. li, p. 134.

[2] F. G. Donnan and B. C. Burt, Journ. Chem. Soc., 1903, vol. lxxxiii, p. 335.

[3] P. Groth, 'Chemische Kristallographie,' 1908, Teil ii, p. 207.

[4] A. Hutchinson, Min. Mag., 1903, vol. xiii, p. 210.

obtained by Mr. Barker, and with the views now held as to the structure and growth of crystals.[1]

I take this opportunity of expressing my thanks to Professor Miers, who allowed me to work in his laboratory, for his suggestions and advice, as well as to Dr. J. J. H. Teall for the loan of material from the Museum of Practical Geology, without which this work could not have been carried out.

Cracow, Austria.

[1] Compare H. A. Miers, 'Some recent research upon the birth and affinities of crystals.' Science Progress, 1907, vol. ii, pp. 121–134.

Some additional localities for Idocrase in Cornwall.[1]

By G. Barrow and H. H. Thomas, M.A., B.Sc.

[Read January 26, 1909.]

THE continuation of the mapping of the aureole of metamorphism round the Bodmin Moor granite has led to the discovery of fresh occurrences of idocrase, developed in the altered, impure limestones. The failure to find this mineral hitherto is now clearly due to the former absence of artificial openings in suitable localities, for the mineral has so far not been found in recognizable form in natural exposures, owing to the rapidity with which these calcareous rocks decompose.

Altered calcareous rocks containing idocrase in considerable abundance have recently been laid open in a small quarry on the west side of the stream at Trenuth Mill, which is about 400 yards south of the granite margin in the well-known Caradon area. The groundmass of the rock here is of a pale green or greenish-grey tint, of almost flinty hardness, and very fine texture; in it are set a number of small lenticular patches, the texture of which is much coarser. These have a well-marked reddish tint and are composed chiefly of garnet and idocrase, the latter being identifiable with a hand-lens by its pale brown colour; the association is thus typical and has been recorded from many areas. The small quarry was opened for road-metal, but the rock has proved so difficult to drill and break up, that the opening is to be filled in, and this locality for idocrase will be practically lost.

The second outcrop of idocrase-bearing rock also occurs in the Caradon area, east of South Yolland Farm and at the same distance (400 yards) from the granite margin; but in this instance there is no true exposure of the rock. Blocks of it, identical with those already described, occur scattered, and in small heaps, along the hedge sides, where they have been deposited after being blasted out of the fields, owing to their proving an obstruction to ploughing. Many interesting specimens of

[1] Communicated by permission of the Director of H.M. Geological Survey. Compare G. Barrow and H. H. Thomas, 'On the occurrence of metamorphic minerals in calcareous rocks in the Bodmin and Camelford areas, Cornwall.' Min. Mag., 1908, vol. xv, pp. 113–123.

altered calcareous rocks, obtained in this manner, may now be found either in a similar position, or built into the field-walls that lie along the outcrop of the calcareous rocks, within the granite aureole of metamorphism. When the Geological Survey map of the district is published showing these outcrops there will be little difficulty in finding localities where excellent examples of the different phases of metamorphism of these calcareous rocks (calc-flintas) may be obtained.

Generally the idocrase does not form good crystals, for the individuals interfere with each other, but occasionally the coarser portions of the rock become somewhat drusy, and in the small cavities well-shaped crystals are fairly common. Where best formed the mineral builds crystals, ranging up to 6 mm. in length and 2 mm. in thickness, of dark to pale brown or amber colour with a somewhat resinous lustre. The crystals are most often attached to the matrix at each end, so that terminal faces can but rarely be observed. The prisms are usually square in section, being bounded by well-developed planes of the form $m\{110\}$; often, however, the form $a\{100\}$ is represented by narrow planes, and modification of the edge $m\,a$ is sometimes noticeable. All the faces of the prism-zone, particularly the form $m\{110\}$, are finely striated parallel to the vertical axis. In some crystals there are indications of terminal faces represented by the basal plane $c\{001\}$ and the pyramid $p\{111\}$, the latter existing as somewhat narrow planes truncating the edges between the base and the prism.

Optically the sign of the zone of elongation is negative, and sections parallel to the basal plane show the emergence of a negative optic axis; no optical anomalies have been detected in those crystals investigated, the mineral being perfectly uniaxial. The prism-zone shows feeble pleochroism, but only where the crystals are fairly thick (0·25 mm. or more); light vibrating parallel to the optic axis is deep brown, and that vibrating at right angles a paler tint of the same colour.

In thin sections the idocrase exhibits certain peculiarities. In all cases it has a very low birefringence, but the value of the double refraction varies considerably, especially in the outer layers of the crystals, and in some instances becomes almost negligible. Sections cut parallel to the vertical axis, between crossed nicols, have the appearance of being polysynthetically twinned, a succession of light and dark bands being especially noticeable towards the outer portion of the crystals. Although these bands are most often arranged parallel to the vertical axis, similar layers may also be noticed crossing the prisms at right

angles. This feature is evidently due to the variation of the intensity of the double refraction in successive zones of growth, for all the layers extinguish simultaneously and have an exactly similar optical orientation. Basal sections show very slight indications of a prismatic cleavage, that parallel to the form $a\{100\}$ being the more distinct.

The mineral differs slightly from that described from Tyland quarry, Camelford,[1] in its deeper colour and its strictly uniaxial character. It is associated with a pale pink to pinkish-brown garnet, pale green pyroxene, and epidote.

The *garnet* is for the most part completely isotropic and much of it is without definite crystalline form. Where, however, crystals have formed they appear to be unmodified rhombic-dodecahedra. The outer layer only of these crystals is occasionally birefringent. Some of the best-shaped crystals are only skeletons, consisting of a thin skin of garnet enclosing granular calcite or some other mineral. Well-formed crystals without inclusions occur completely embedded in optically continuous idocrase, while some skeleton-garnets are surrounded by idocrase and have an infilling of the same mineral in optical continuity with that outside; this feature was also noted in the case of skeleton-garnets occurring in the epidote mentioned below.

The *pyroxene* is a diopside forming somewhat irregular small patches. It is elongated parallel to the intersection of the cleavages, but shows no traces of terminations. The zone of elongation is positive, and sections parallel to the plane of symmetry $b(010)$ give an extinction of about 25°. In thin sections it is colourless.

The *epidote*, which occurs in grains and crystalline aggregates, has an exceedingly low extinction and birefringence for this mineral, and thus most probably approximates to the clinozoisites. A more ferruginous variety with sensible pleochroism in shades of yellow also occurs sparingly. It encloses irregular patches and skeleton-crystals of garnet.

[1] G. Barrow and H. H. Thomas, Min. Mag., 1908, vol. xv, p. 121.

Detrital Andalusite in Tertiary and Post-tertiary sands.[1]

By H. H. Thomas, M.A., B.Sc.

[Read January 26, 1909.]

UNTIL quite recently, in spite of its characteristic features, andalusite had not been met with in the younger detrital rocks of Britain; a few years ago, however, I remarked on its relative abundance in the older Pliocene sands of St. Erth and St. Agnes in the west of Cornwall.[2] Its presence in these deposits, in which it is associated with pink garnet and cyanite, is easily explained by the close proximity of the areas of deposition to the metamorphic aureoles of the west of England granite-masses, in which andalusite of identical character is exceedingly common. It also occurs in fair quantity in the Pliocene sands of Lenham in Kent accompanied by cyanite, and together with cyanite and garnet in the Red and Norwich Crags and the Chillesford Beds in the east of England.[3] It is said to be rarely present in the Chalk of Beer Head, Dorsetshire,[4] but I have failed to find it in the residues which I have examined.

Records of detrital andalusite in the unaltered state from foreign localities are quite few, the most noteworthy being those made by R. Bréon and E. Artini. R. Bréon[5] mentioned it as being fairly common in the sea-sands of the Île-de-Groix (Brittany) and as of rare occurrence in the dune-sands of Pointe-de-Grave (Landes), in both cases associated with garnet, but cyanite, its usual companion, is not recorded. E. Artini[6] has noted it in the sands of the Ticino, near Pavia, with cyanite, garnet, and many other minerals; and, with the same associates, from the sands

[1] Communicated by permission of the Director of H. M. Geological Survey.

[2] H. H. Thomas, Quart. Journ. Geol. Soc., 1902, vol. lviii, p. 620.

[3] Ibid., 1900, vol. lvi, pp. 38–43.

[4] W. F. Hume in 'Cretaceous Rocks of Britain,' vol. ii (Mem. Geol. Surv.), 1903, p. 510.

[5] R. Bréon, Bull. Soc. Min. France, 1880, vol. iii, p. 46.

[6] E. Artini, Giorn. Min. crist. Ital., 1891, vol. ii, pp. 1–19, also p. 177; Riv. Min. crist. Ital., 1898, vol. xix, pp. 33–34.

of the river Adige in northern Italy. It has also been mentioned as occurring in the marine monazite-bearing sands of the neighbourhood of Penang in the Malay States.[1]

Recently my attention has been drawn to masses of glacial sand and gravel which cap many of the minor elevations in western Carmarthenshire and the counties of Pembroke and Cardigan, as well as to some of the drift-sands of north Wales and the beach- and blown-sands of the same districts. Many of the masses of drift-sand were mapped by my colleagues Mr. T. C. Cantrill, Mr. E. Dixon, and Mr. O. T. Jones, who kindly furnished me with samples. In almost every case, andalusite, in a perfectly fresh condition, proved a fairly common constituent, but more especially of those samples of sand collected from south-west Wales.

It is an interesting point that, with the possible exception of the Chalk of Beer Head, all the known records of unaltered detrital andalusite are from beds of comparatively recent date, and that it as yet remains undetected in any sedimentary rock of greater antiquity than the Pliocene. Considering the work that has been done on the Cretaceous and older Tertiary rocks by Cayeux, Dick, Hume, and others, it would be most surprising that this mineral, had it been present, should have remained unidentified. It therefore appears that andalusite has not survived as such in the Cretaceous and Lower Tertiary rocks of the London and Paris basins. In all the older British sediments that I have examined, including the Old Red Sandstone, Carboniferous, Permian and Triassic sandstones, as well as Jurassic sands, no unaltered grain of this mineral has been detected.

It is, therefore, highly probable that andalusite cannot remain in a sand without decomposition for more than a limited period, after which its place is taken by certain micaceous aggregates, such as are of frequent occurrence in the Triassic sandstones of the west of England.

It may, I think, be taken for granted that the presence of unaltered andalusite in a glacial or recent sand means that much of the detritus has been furnished either directly by some metamorphic area, or indirectly by Tertiary sediments derived in part from similar or identical metamorphic masses.

Andalusite-bearing rocks are of restricted occurrence in the British Isles and the presence and distribution of detrital andalusite in recent sedimentary rocks should point more or less clearly to some special area of metamorphic rocks. In the case of the drift-sands of west Wales two near sources are available—either the granitic regions of Cornwall and

[1] Bull. Imp. Inst., 1906, vol. iv, p. 301.

Devon or those of the east of Ireland. It is not, however, my purpose in this short note to discuss the source of the mineral or its associates, but merely to put on record those sands and those localities in which detrital andalusite has been found.

In the superficial sands of west Wales it occurs as slightly elongated, somewhat angular grains averaging 0·43 mm. in length, 0·25 mm. in breadth, and 0·12 mm. in thickness.[1] Occasionally there are some signs of rounding.

The elongation is that usually met with in andalusite, namely parallel to the a-axis, while the grains are bounded by the good cleavages parallel to the prism {110}. The sign of the zone of elongation is always negative, and this forms a ready means of distinguishing andalusite from certain members of the rhombic-pyroxene group with which it might possibly be confused. The pleochroism exhibited by some grains is most intense, reaching occasionally a blood-red colour for light vibrating parallel to the axis of elongation (a) and pale greenish-blue at right angles. This latter tint is produced by the mixture of the tints due to rays vibrating parallel to b and c, as the normal to the plane of the cleavage makes an angle of approximately 45° with the points of emergence of those axes.

A few grains viewed in convergent light show a positive bisectrix (Bx_o) and are evidently tabular parallel to the less perfect cleavage {100}. They usually show the characteristic rose-pink colour for light vibrating parallel to a and the pale green parallel to b. The pleochroism, however, is far from a constant feature, for many grains which have a similar orientation and thickness to those showing strong pleochroism are almost colourless for all positions of the polarizer. The intensity of the pleochroism often varies abruptly in the same grain, causing deeply coloured layers ranging up to 0·07 mm. in thickness, which evidently represent zonal layers in the original crystals.

Almost every grain possesses rod-like and granular, dark, opaque inclusions, arranged parallel to the vertical axis.

The associates of andalusite in the sands of west Wales are pink garnet, sometimes in well-formed dodecahedra, greenish-brown augite, cyanite, zircon, rutile, tabular anatase, staurolite, brown and more rarely blue tourmaline, green hornblende, bright green epidote, rare cordierite, iron ores, and in some cases glaucophane.

[1] The thickness of the grains was obtained by measuring the retardation on the cleavage-plane, assuming that for andalusite $\gamma - \alpha = 0{\cdot}011$, which gives the value 0·0086 for the birefringence on (110).

The sands and localities from which andalusite has been recognized in Wales are as follows:—

Glacial sands from Castle-tôch and Ebenezer, near Llansadurnen,[1] and Red Roses in Carmarthenshire; Pen-cnwc near Llandissilio East, Colby Moor near Llawhaden, Carew Cheriton, Carew Newton, and Bubbleton in Pembrokeshire; and about two miles south-east of Mount Church in Cardiganshire. It is present, but extremely rare, in the glacial sands of Bagillt in Flintshire. It occurs in the beach- and blown-sands of Laugharne in Carmarthenshire, Newgale in Pembrokeshire, and Mount Church in Cardiganshire.

In putting forward the above records and description of detrital andalusite in England and Wales, I do so with the suggestion that a detailed study of the distribution of this highly characteristic mineral will throw additional light on the source of the glacial deposits of south and west Wales, or indicate the possible extension of the younger Tertiary deposits beyond the limits at present recognized.

[1] These sands are described in 'The Country around Carmarthen', Mem. Geol. Surv. (in the press).

The energy of twin-crystals.

By Harold Hilton, M.A.

[Read January 26, 1909.]

VERNADSKY [1] has pointed out that in certain cases a twin-crystal appears to be a more stable form than the simple polyhedron, as proved by Scacchi's observation that twins sometimes exceed in magnitude and regularity simple crystals growing in the same solution. He suggests that an explanation can be found in the fact that the surface-energy may be less for a twin than for a simple crystal of the same volume. The suggestion is a valuable one, but Vernadsky applies no quantitative test to his theory. I have therefore thought it worth while to work out the simplest case, which seems to be the following :—

Suppose we have a simple crystal as shown in fig. 1, and also a twin by reflection on a face f (the right-hand face of fig. 1) having the same

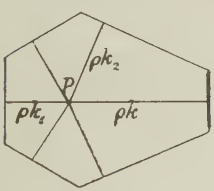

Fig. 1.

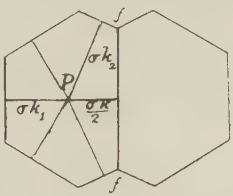

Fig. 2.

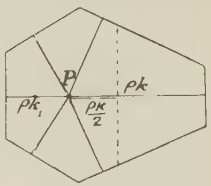

Fig. 3.

combination of faces as the simple polyhedron except that f is now a composition-plane. Then for the simple crystal it is known that, if k, k_1, k_2, k_3, ... are the capillarity-constants (surface-energies per unit area) of the faces, there is a point P inside the crystal whose distances from the faces are ρk, ρk_1, ρk_2, ρk_3, ... ; where $\rho = 3V/E$, V being the volume of the crystal and E its total surface-energy.[2] This is assuming that disturbing influences are eliminated during growth, so that the crystal may be considered as having its normal habit, in which

[1] W. Vernadsky, 'Beiträge zur Energetik der Krystalle.' Zeits. Kryst. Min., 1908, vol. xlv, pp. 124–142.

[2] See Hilton's 'Mathematical Crystallography', 1903, p. 107. With the notation there used $n'_t = \rho k_t$, and therefore $3V = \Sigma n's = \rho \Sigma ks = \rho E$.

the total surface-energy for a given volume and combination of faces is a minimum.

To find the normal shape of the twin-crystal of fig. 2, let κ be the surface-energy per unit area of the composition-plane. Then we may assume that the shape is the same as if, firstly, each of the component crystals had grown independently so that the face f had the capillarity-constant $\kappa/2$, and the remaining faces had capillarity-constants $k_1, k_2, k_3, \ldots$ as before; and, secondly, the crystals were afterwards united along the face f without gain or loss of energy. Then there is a point inside each crystal of the twin such that the perpendiculars from it on the composition-plane and faces are $\sigma\kappa/2$, σk_1, σk_2, σk_3, ..., where

$$\sigma = \frac{3 \times \text{volume of each crystal}}{\text{surface-energy of each crystal}} = \frac{3 \times \text{volume of whole twin}}{\text{surface-energy of whole twin}}.$$

If the simple polyhedron and twin have equal volumes, the former or the latter has the less surface-energy, i. e. is the more stable, according as ρ or σ is the greater.

In other words (remembering that the ratio of volume to energy increases as the volume increases [1]), if in fig. 1 the plane parallel to f and distant $\rho\kappa/2$ from P cuts off more than half the crystal, the twin is more stable than the simple crystal with the same volume (see fig. 3).

If the crystal of fig. 1 has a symmetry-plane parallel to f, the twin by reflection becomes a parallel growth. In this case $\kappa = 0$, and P is the centre of the crystal. We see that two crystals forming a parallel growth will be in general less stable than the single crystal of the same volume.

The following is a list of some papers on this subject. Quantitative experiments on the habit of crystals are badly needed, and would doubtless lead to valuable results.

P. Curie, Bull. Soc. franç. Min., 1885, vol. viii, p. 145.

G. Wulff, Zeits. Kryst. Min., 1901, vol. xxxiv, p. 520.

H. Hilton, Centralblatt Min., 1901, p. 753; Phil. Mag., 1902, ser. 6, vol. iii, p. 144.

W. Vernadsky, Zeits. Kryst. Min., 1908, vol. xlv, p. 124.

Bedford College,
London.

[1] The volume increases as the cube, and the surface-energy as the square of the linear dimensions of the crystal.

On the identity of Guarinite and Hiortdahlite.

By Dr. F. Zambonini,

Of the University of Naples.

With a note on the chemical composition of Guarinite.

By G. T. Prior, M.A., D.Sc., F.G.S.

Assistant in the Mineral Department of the British Museum.

[Read March 23, 1909.]

Literature.

1. G. Guiscardi, Mem. R. Accad. Sci. Napoli, 1857, vol. ii, p. 408.
2. V. v. Lang, Tschermak's Min. Mittheilungen, 1871, p. 81.
3. A. Brezina, Ibidem, 1874, p. 285.
4. A. Des Cloizeaux, 'Manuel de Minéralogie,' 1874, vol. ii, p. xxiii.
5. G. Guiscardi, Rend. Accad. Sci. Napoli, 1876, vol. xv, p. 10.
6. J. A. Krenner, Földtani Közlöny, 1888, vol. xviii, p. 153.
7. F. Mauro, in A. Arzruni, 'Physikalische Chemie der Krystalle,' 1893, p. 48.
8. O. Rebuffat, Laboratorio chimico R. Scuola Ingegneri, Napoli, 1894, p. 1.
9. F. Zambonini, Centralblatt Min., 1902, p. 523.
10. W. C. Brögger, Zeits. Kryst. Min., 1906, vol. xlii, p. 432.

ALTHOUGH more than fifty years have passed since Guiscardi published the first description of guarinite, the true nature of this mineral has never yet been ascertained. As regards the crystalline form, Guiscardi's first idea was that the crystals of guarinite are orthorhombic (he had himself reckoned the ratio $a : b = 0{\cdot}9896 : 1$; see literature, nos. 3 and 5); but, having observed crystals with a tetragonal habit, he finally decided to describe the mineral as tetragonal-hemihedral. V. v. Lang by his optical investigations appeared to place the orthorhombic symmetry of guarinite beyond doubt, and Des Cloizeaux later published a note on a combination observed by him.

Some years ago I published the results of some crystallographic and optical investigations on guarinite and also came to the conclusion that the mineral was orthorhombic, although I had observed irregularities in the angles on some crystals.

As regards the chemical composition of the mineral, Guiscardi's analysis (see under I) made it practically identical with sphene; Mauro, however, many years later, discovered that the mineral contains no titanium, and Rebuffat soon afterwards made a new analysis the result of which is given under II:—

	I. Guarinite (Guiscardi).	II. Guarinite (Rebuffat).	III. Hiortdahlite (Cleve).
SiO_2	33·64	34·84	31·60
TiO_2	33·92	—	1·50
ZrO_2	—	—	21·48
Al_2O_3	—	25·37	—
Fe_2O_3	trace	1·69	0·34
FeO	—	—	0·94
Y_2O_3 (?) ...	—	1·23	—
Ce_2O_3	—	3·45	—
MnO	trace	—	0·96
CaO	28·01	25·20	32·53
MgO	—	—	0·10
Na_2O	—	6·57	6·53
K_2O	—	1·56	—
H_2O	—	—	0·58
F	—	—	5·83
	95·57	99·91	102·39
		O for F_2	2·43
			99·96

The view of Guiscardi that guarinite is an isomeric modification of the compound—$CaTiSiO_5$—already known as titanite, had therefore to be given up. I had at my disposal (in 1902) only a very small amount of material and could establish only the absence of titanium and the presence of sodium. Krenner had remarked on the similarity of the crystalline form of guarinite and pseudobrookite; I, however, pointed out a closer resemblance between the mineral and danburite and was of the opinion that it should be placed in the danburite group. This view was adopted by Brögger.

My doubts as to the true nature of guarinite still remained, and I often sought on the ground of the above data to refer it to a known silicate, but without success. It was only at the end of 1906 that I discovered the clue to the problem. In the course of an investigation on the sanidinite of Monte Somma I found some small crystals which, by their crystallographic characters, could only be referred to hiortdahlite; and there was no difficulty in placing beyond doubt the identity of these small crystals with actual guarinite crystals in the mineralogical collection of the University of Naples. A comparison of the angles of guarinite and hiortdahlite then showed that these minerals can be regarded as crystallographically identical or very similar. If we take the forms $\{0kl\}$[1] observed by Guiscardi and me as $\{h0l\}$, we obtain the following table of comparison of angles for forms which have been observed on both minerals:—

Guarinite.[2]		Hiortdahlite.[3]
$(100):(110) = 44° 47\frac{1}{2}'$	...	$(100):(110) = 44° 54'$ $(100):(1\bar{1}0) = 44\ 59\frac{1}{2}$
$(100):(210) = 26\ 23\frac{3}{4}$	...	$(100):(210) = 26\ 30$ $(100):(2\bar{1}0) = 26\ 32\frac{1}{2}$
$(100):(120) = 63\ 16$	...	$(100):(120) = 63\ 18\frac{1}{2}$ $(100):(1\bar{2}0) = 63\ 25$
$(100):(101) = 69\ 41\frac{1}{2}$	...	$(100):(101) = 70\ 4$

As seen in the table, the correspondence in angles is very satisfactory. There is also a similar correspondence in the colour, hardness, and specific gravity of the two minerals. In the chemical characters also guarinite and hiortdahlite are very similar: both fuse fairly easily before the blowpipe and are decomposed by acids. Finally, by comparing the analyses of guarinite with that of hiortdahlite which we owe to Cleve (see under III above) we remark at once, especially in the case of the analysis of Rebuffat, a very striking correspondence, if we consider that

[1] That this is so will be proved later. Guiscardi took the terminal form observed by him as $\{0kl\}$ without optical examination; and the crystal on which I measured $\{011\}$ was not transparent, and was therefore unsuitable for optical determination. In the course of the new investigation of guarinite, I had sections cut from the crystals which still remained in my possession, and so was able to convince myself easily that the terminal form is to be regarded as $\{101\}$. In fig. 3 of my paper of 1902 the axes a and b should be interchanged.

[2] According to my measurements.

[3] According to Brögger, Zeits. Kryst. Min., 1890, vol. xvi, p. 369.

the precipitate produced by ammonia should be referred, not really to titanium or aluminium as Guiscardi and Rebuffat respectively believed, but to zirconium. This idea is supported by the fact that Guiscardi did not test for zirconium at all and Rebuffat only did so on a small, separate part of the precipitate obtained by ammonia, and only by means of the turmeric-paper reaction. This view of the composition I was soon able to confirm, as I was fortunate enough to obtain proof by means of Ruer's microchemical test that zirconium is an essential constituent of guarinite. I then undertook a new and complete crystallographic and optical investigation of guarinite in order to determine whether the similarities between guarinite and hiortdahlite are sufficiently close for their specific identity.

In the present paper I content myself with giving only such data as will suffice in order to place the identity of the two minerals beyond doubt, leaving for a later publication a more detailed monograph on the properties, occurrence, &c., of the Vesuvian mineral.

The new investigation was rendered difficult by the fact that guarinite crystals are not only rare but almost always unsuitable for exact measurements. Crystals provided with terminal faces which allow of a fairly exact determination are a rarity; the majority of the guarinite crystals consist of tufts with very complicated structure and imperfect parallel intergrowth or sheaf-like grouping. The faces of the zone [001], which is the one most perfectly developed, are very often striated or notched or so small that they give broad or nearly unrecognizable images. It must also be mentioned that the guarinite crystals are generally cracked or bent and re-cemented again, in the same way as, according to Brögger, are crystals of hiortdahlite. In spite of all these difficulties, some crystals were found which were suitable for exact investigation.

As regards the crystallographic orientation, I have chosen as $\{100\}$ that one of the two pinacoids approximately at right angles in the principal zone of guarinite which shows practically no pleochroism under the microscope. We see then that the guarinite crystals are very generally tabular to $\{100\}$; only rarely does $\{010\}$ predominate over $\{100\}$. Moreover, the crystals with pseudo-tetragonal habit, on which $\{100\}$ and $\{010\}$ are approximately of equal size, are very rare and consist mostly of the union of numerous crystals tabular to $\{100\}$. In the zone [001] I have observed, besides the two pinacoids $a\,\{100\}$ and $b\,\{010\}$, also the forms $m\,\{110\}$, $M\,\{1\bar{1}0\}$, $l\,\{210\}$, $h\,\{2\bar{1}0\}$, $g\,\{120\}$ and $k\,\{1\bar{2}0\}$. On many crystals each pinacoid $\{hk0\}$ is associated with the corresponding $\{h\bar{k}0\}$, and then the zone [001] is pseudo-ortho-

rhombic; but generally this is not the case, and the zone [001] has clearly a triclinic development. When exact measurements are possible, differences are always observed in the angles which should be equal if guarinite were orthorhombic; in my work of 1902 I mentioned a crystal on which I measured

$$(010):(110) = 45^\circ\ 2'; \quad (010):(\bar{1}10) = 45^\circ\ 32'.$$

At that time I explained this difference in angles as due to the geometrical variations so common in the minerals (sanidine, idocrase, &c.) of the volcanic bombs; but the new measurements, which have shown the constancy of the phenomenon, as well as the optical data, no longer allow such an explanation to hold good; they show, in fact, that guarinite is not to be regarded as orthorhombic with angular variations, but as really triclinic. Thus, on four crystals, measurement of the angle $(100):(0\bar{1}0)$ gave me $90^\circ\ 7'$, $90^\circ\ 2'$, $90^\circ\ 7'$, $90^\circ\ 6'$, $90^\circ\ 5'$: for hiortdahlite Brögger found $90^\circ\ 5\frac{1}{2}'$. The other angles of the zone [001] admitted of somewhat less exact measurement, still they agree quite well with the values which Brögger has calculated for hiortdahlite.

	Guarinite (measured).		Hiortdahlite (Brögger).
$(100):(110)$	$= 44^\circ\ 52'$	...	$44^\circ\ 54'$
$(100):(2\bar{1}0)$	$= 26\ 36$	...	$26\ 32\frac{1}{2}$
$(010):(120)$	$= 26\ 28$	...	$26\ 36$

But more important than the angles of the zone [001] are those of the terminal forms, which gave me the clue to the identity of the minerals. Guarinite crystals with well-developed end-faces are extremely rare: the crystals are usually terminated quite irregularly or with a dull, rough, completely unmeasurable basal plane. The first crystal on which I was able to make approximate but satisfactory measurements of the terminal forms is the crystal represented in fig. 1. It is very small, and is tabular parallel to $\{100\}$: in the zone [001] were, besides $a\ \{100\}$, also the forms $l\ \{210\}$ very small, $m\ \{110\}$ somewhat larger, $M\ \{1\bar{1}0\}$, $h\ \{2\bar{1}0\}$, and $b\ \{010\}$: a terminal face was also present. The crystal had a decidedly triclinic aspect, and was very similar to fig. 1, plate XVII of Brögger's paper, so that I supposed that the crystal must be hiortdahlite. In fact the measurements showed that the observed terminal face of the guarinite crystal exactly corresponds to the form $e\ \{1\bar{1}1\}$ of hiortdahlite.[1]

[1] Throughout this paper I refer always to the first mode of orientation of hiortdahlite adopted by Brögger.

Guarinite (measured).		Hiortdahlite (Brögger).
$(100):(1\bar{1}1) = 71°\ 48'$ ...	...	71° 12′
$(0\bar{1}0):(1\bar{1}1) = 70°$ about	...	71 13

The crystal represented in fig. 2 gave better measurements, the forms corresponding exactly to those of $p\ \{111\}$, $e\ \{1\bar{1}1\}$, $r\ \{\bar{1}11\}$, $q\ \{\bar{1}\bar{1}1\}$ of hiortdahlite, as the following measurements show.

Guarinite (measured).				Hiortdahlite (Brögger).
$(100):(11\bar{1}) = 72°\ 27'$ ...	...	...	...	72° 12′
$(100):(1\bar{1}1) = 72°$ about	...	...	...	71 12
$(0\bar{1}0):(1\bar{1}\bar{1}) = 71\ 39$ ...	...	...	...	71 $10\frac{1}{2}$
$(010):(111) = 72\ 23$ ...	...	...	...	72 $13\frac{1}{2}$

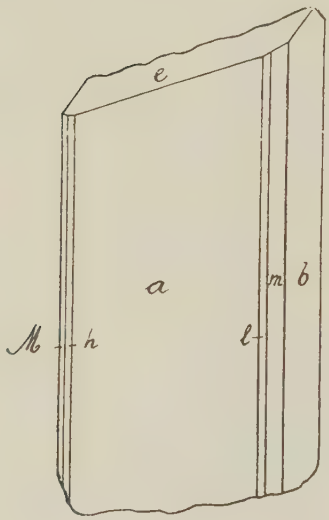

Fig. 1.

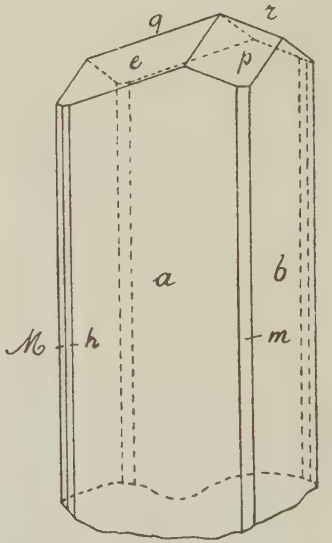

Fig. 2.

Crystals of Guarinite.

The crystal shown in fig. 3 is very interesting: in the zone [001] it has a very pronounced triclinic habit on account of the complete failure of $\{2\bar{1}0\}$ and $\{110\}$. The terminal forms are $t\ \{201\}$, which is the largest face, $v\ \{101\}$, and $d\ \{102\}$: only $\{201\}$ allowed of good measurement. I found:

Guarinite (measured).				Hiortdahlite (Brögger).
$(100):(201) = 53°\ 40'$	...	...	...	54° 28′
$(100):(101) = 70°$ about	...	...	...	70 4
$(100):(102) = 80$,,	...	...	...	79 26
$(010):(201) = 90\ 54$	...	...	...	90 27

This crystal is like the figures of Guiscardi, which represent tabular guarinite crystals; the tabular face, however, is certainly {100}, as I have shown optically, so that the terminal forms are {*h*0*l*} and not {0*kl*}. It must be mentioned also that I have observed on some crystals {0*kl*} or forms vicinal to these, though always so imperfect as to allow only of rough measurements. It must not be forgotten also that the angles (010):(011) = 71° 13′ and (0$\bar{1}$0):(0$\bar{1}$1) = 70° 5½′ are not very different from the angles (010):(111) = 72° 13½′ and (0$\bar{1}$0):(1$\bar{1}$1) = 71° 13½′, so that if the faces of {100} are not measurable, it is not possible to distinguish with certainty the forms {011} and {0$\bar{1}$1} from {111} and {1$\bar{1}$1}. On the crystal which is represented in fig. 4 of my work of 1902, according to the new measurements I have made, there appear to be present also the forms {011} and {0$\bar{1}$1}; these were, however, scarcely measurable.

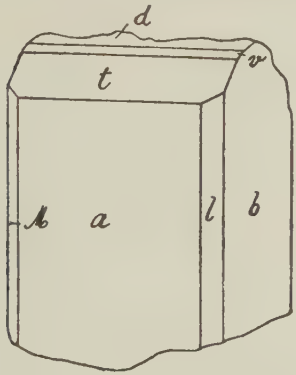

Fig. 3.

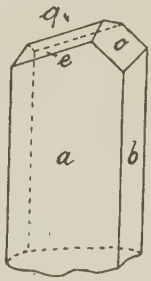

Fig. 4.

Crystals of Guarinite.

Lastly, the crystal represented in fig. 4 presents some remarkable features. Besides the forms represented, there are also present traces of pinacoids {*hk*0} and {*hk̄*0}. The terminal forms are *e* {1$\bar{1}$1} and *q* {$\bar{1}$1$\bar{1}$}, both small, and one good face with the symbol *o* {273}, which gave good measurements, not only {273} but also {100} and {010} giving good reflections.

Guarinite (measured).		Hiortdahlite (Brögger).
(100):(273) = 79° 10′	... ...	79° 9′
(010):(273) = 51 41	... ...	51 50½
(0$\bar{1}$0):(1$\bar{1}$1) = 71 30	about	71 13
(100):(1$\bar{1}$1) = 71 30	„	71 12
($\bar{1}$00):($\bar{1}$1$\bar{1}$) = 72	„	72 12

Of the terminal forms mentioned up to the present $p\{111\}$, $e\{1\bar{1}1\}$, $r\{\bar{1}11\}$, $q\{\bar{1}\bar{1}1\}$, are new for guarinite; they are, however, characteristic faces on hiortdahlite[1]; $t\{201\}$ is new for hiortdahlite, and $d\{102\}$ and $o\{273\}$ have not hitherto been observed either on hiortdahlite or on guarinite. Without giving further data from my measurements of other guarinite crystals, it appears to me that the above are quite sufficient in order to prove the crystallographic identity of hiortdahlite and guarinite. The small differences which were observed in some angles between the measured and calculated values are of little importance and for the most part are to be ascribed to the uncertainty of the measurements: the more exact measurements are in close agreement with the calculated. It is quite possible also that guarinite possesses geometric constants which vary a little from those of hiortdahlite; for it has been established that the crystals of a mineral which occur in volcanic bombs generally give axial ratios varying somewhat from those of crystals of the same mineral coming from older eruptive rocks.

We now come to the optical characters of guarinite[2]. I had already stated in 1902 that guarinite crystals do not generally extinguish uniformly between crossed nicols. At that time I sought to explain the phenomenon by the complicated structure of $\{100\}$ and $\{010\}$, which are often divided into numerous facets. My new observations have, however, proved this view to be quite untenable, because the crystals with quite smooth $\{100\}$ and $\{010\}$ show exactly the same behaviour. Thin slices cut from good crystals parallel to $\{100\}$ and $\{010\}$ have, on the other hand, shown clearly that the failure to give a definite and regular extinction depends on the fine polysynthetic twinning of the guarinite crystals. Thin slices in fact afford clear proof, not only of the triclinic symmetry of guarinite, but also of the identity of guarinite and hiortdahlite.

[1] $\{\bar{1}11\}$ is not given by Brögger in the list of forms, but occurs in the table of angles.

[2] These optical characters of the guarinite crystals, which I have repeatedly observed, and of the correctness of which there is no doubt, vary from those given in my work of 1902. My determinations were made at that time on a very beautiful crystal which came from the greyish-violet trachyte with melanite, and unfortunately was afterwards lost. That crystal was, however, not guarinite, but rather danburite, or a mineral near to danburite; this would explain the wonderful similarity which was found between the supposed guarinite and danburite. That the crystal which was examined was not guarinite is evident from the fact that it showed uniform extinction, and had the plane of the optic axes exactly parallel to $\{001\}$, with exactly perpendicular emergence of the mean lines on the forms regarded as $\{100\}$ and $\{010\}$. These characters do not at all agree with those of true guarinite.

In sufficiently thin slices parallel to {100} one remarks between crossed nicols an apparently nearly homogeneous portion and another which consists of more or less broad lamellae in twin position to each other. The apparently almost homogeneous portions show, if a gypsum-plate or a stronger magnification be used, a very fine and complicated polysynthetic structure. The bounding lines of the polysynthetic lamellae are straight and parallel to the vertical axis. The individual lamellae extinguish right and left under an angle of 22°–24° with the vertical axis: in hiortdahlite the angle is about 25°. The polysynthetic structure of hiortdahlite crystals is often so fine that the extinction in thin sections is only imperfect and the single lamellae are not plainly recognizable: with stronger magnification and the use of the gypsum-plate, the polysynthetic structure becomes evident. Guarinite according to this behaviour must be regarded as a polysymmetric substance (in Groth's sense): according to the fineness of the polysynthetic lamellae there is a greater or less approximation to the optical behaviour of an orthorhombic crystal.

Thin slices parallel to {010} also showed a very pronounced polysynthetic structure. The twin-lamellae are much smaller than those which are observed in the slices parallel to {100}; they also are parallel to the vertical axis. On the most distinct lamellae the extinction angle with the vertical axis amounts to 14° ($15\frac{1}{2}$° on hiortdahlite according to Brögger).

All these observations agree perfectly with those which Brögger has made on hiortdahlite, and we can therefore conclude that the guarinite crystals, like the polysynthetically composed crystals of hiortdahlite, represent twins belonging to the triclinic system, according to the twin-law: twin-axis, the vertical axis; plane of composition, {100}. It must be remarked, however, that guarinite crystals generally show other lamellae, which are otherwise orientated than those mentioned above: they obey therefore other twin-laws: unfortunately no certain conclusions on this point could be drawn from the material at my disposal.

The acute bisectrix emerges through {100}, and the obtuse bisectrix through {010}. The acute bisectrix is the axis of least elasticity, so that guarinite is optically positive: the direction of vibration which makes the smallest angle with the axis *c* on the two pinacoids {100} and {010} approximates to the optic normal. The axial angle is large, the dispersion considerable, and probably $\rho < v$.

On {100} the pleochroism is scarcely observable; on {010}. on the other hand, it is distinct. We have $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. $\mathfrak{c}$ is orange-yellow,

wine-yellow, or very bright yellow, according to the intensity of colour of the crystal examined, and of course of the thickness of the plate. **b** is a very pale yellow, nearly colourless; **a** almost perfectly colourless, being almost equal to **b**. The correspondence with hiortdahlite is in this respect perfect.

Guarinite shows no good cleavage; thin slices parallel to {010} show numerous cracks, corresponding to the cleavage along {100} already observed in 1902. In thin slices parallel to {100} one sees occasionally straight cleavage-cracks which make with the axis *c* an angle of about 44° and correspond therefore to pinacoids {031} and {0$\bar{3}$1}; generally cleavage-cracks are observed only parallel to one of these pinacoids, while according to Brögger in hiortdahlite they are parallel to both. Other rare and more obscure cleavage-cracks are fairly symmetrical to the vertical axis, with which they make an angle of about 37°; cleavage-cracks parallel to {010} are almost imperceptible.

Perfectly pure guarinite crystals, according to my determinations made by the suspension method, have a specific gravity = 3·196[1]: for hiortdahlite Brögger and Cleve found 3·267 and 3·235 respectively: the correspondence with guarinite is satisfactory. The value found by Guiscardi 3·487 is decidedly wrong, as was already shown in 1902.

From the preceding we can therefore conclude that guarinite and hiortdahlite possess the same crystallographic and physical characters: and since both are essentially silico-zirconates (having regard to my micro-chemical test on guarinite) of calcium and sodium, it is practically certain that the two minerals are identical. It appeared to me desirable, however, by a new and exact analysis of guarinite to establish the true quantitative composition of this mineral, more especially as we have only one analysis of hiortdahlite. To prepare sufficient material for the analysis was extremely difficult owing to the rarity of the mineral. After long and tedious picking out of crystals from numerous pieces of sanidinite, I was successful in collecting about 0·4 gram of almost perfectly pure material. The analysis was undertaken by my friend Dr. G. T. Prior, to whom it is my pleasant duty to offer my most hearty thanks.

Dr. Prior's investigations have completely established my view as to the identity of guarinite and hiortdahlite. Some of the numbers obtained by him on guarinite, especially as regards the fluorine, do not agree very well with those given by Cleve for hiortdahlite; but if we

[1] Prior's determination with the pycnometer gave 3·25 (see p. 257).

consider guarinite and hiortdahlite to be complicated solid solutions, we must conclude that the smaller content of fluorine and the presence of some niobic instead of titanic acid do not suffice to justify the separation of guarinite as a variety of hiortdahlite.

The chemical composition of Guarinite.[1]

(By G. T. Prior.)

The material placed at my disposal for analysis consisted of small fragments of crystals. These were crushed to a coarse powder from which a little felspar was removed by suspension in methylene iodide diluted with benzene. The specific gravity of the material thus purified was 3·25, as determined by means of a 3 cc. pycnometer on 0·3601 gram.

Since previous analyses of guarinite have afforded such varying results, it seems advisable to give a somewhat detailed description of the methods adopted in the present analysis.

The finely powdered mineral was decomposed by concentrated sulphuric acid. In the course of this operation the attempt was made to collect any fluoride of silicon which might be given off, since the mineral presumably contained a large percentage of fluorine. For this purpose the material was placed in a platinum retort provided with inlet and outlet tubes of platinum, through which a current of dry carbon dioxide was passed during the decomposition. The narrow outlet tube was connected with a wider tube of platinum which dipped into a strong solution of potassium fluoride contained in a long narrow platinum crucible. Only about a milligram of potassium silico-fluoride, insoluble in alcohol, was, however, obtained in this way, a result which gave the first indication that the mineral did not contain such a high percentage of fluorine as hiortdahlite.

After the decomposition of the mineral, the solution was diluted, warmed, and filtered from the silica, which was weighed and afterwards tested for purity in the usual way by means of hydrofluoric acid. The filtrate from the silica was largely diluted and heated for many hours with renewal of water. A slight precipitate which separated was collected, and after testing for silica by hydrofluoric acid, was fused with acid sulphate of potassium. On treating with water, the whole remained as an insoluble residue, for in the filtrate no coloration was given with

[1] Communicated by permission of the Trustees of the British Museum.

hydrogen peroxide (absence of titanic acid) and no precipitate with ammonia. The insoluble residue consisted mainly of niobic acid, only a few needles of the tantalum double fluoride being obtained on treating the hydrofluoric acid solution with hydrogen-potassium fluoride.

After the separation of the precipitate of niobic acid from the original solution, the filtrate was evaporated to dryness and the excess of sulphuric acid was expelled. The residue dissolved to a clear solution in cold water, but on boiling a slight precipitate coloured red with iron separated. In the filtrate from this precipitate a double precipitation with ammonia was made. The precipitate obtained on boiling and the ammonia precipitate were dealt with separately but in the same way, and both were found to consist only of zirconia and oxide of iron. The method of treatment of the two precipitates was as follows. They were brought into solution in sulphuric acid, and the zirconia was separated from the iron by precipitation with sodium thiosulphate. The precipitate was converted into chloride, in the nearly neutral solution of which oxalic acid produced a bulky precipitate completely soluble in excess of the reagent (ZrO_2). The filtrate from the thiosulphate precipitate after freeing from sulphur, oxidizing, &c., gave no precipitate with oxalic acid (absence of cerium and yttrium earths), but only contained a little iron.

The zirconia from the oxalic acid solution was tested in the following way. Converted into sulphate, it was precipitated by excess of potassium sulphate. The solution in hydrochloric acid gave on evaporation the characteristic needles of zirconium oxychloride. No alumina was obtained in the filtrate after precipitating with excess of potash. The potash precipitate was completely soluble in dilute hydrofluoric acid (absence of cerium, yttrium, &c.). The solution of the chloride, strongly acidified with sulphuric acid, gave with sodium phosphate a bulky gelatinous precipitate of zirconium phosphate.

In the filtrate from the ammonia precipitate of zirconia and oxide of iron, the lime, manganese, and alkalis were determined by the usual methods. A blank experiment was made for alkalis, using approximately the same amount of water and reagents (sulphuric acid, ammonia, &c.) as in the analysis. About a milligram of alkalis was obtained and deducted from the weight of alkalis obtained in the analysis. This main analysis was made on 0·3341 gram.

For the determination of water and fluorine only 0·0612 gram of material was available, and the numbers obtained are given for what they are worth. For the determination of water, the mineral was heated with oxide of lead. The loss of weight (corresponding with 0·81% H_2O)

only amounted to about half a milligram, and the result is uncertain, for no trace of water could be detected on heating a few grains of the pure mineral in a closed tube. For the determination of fluorine, the material mixed with oxide of lead which had served for the water determination was used. It was fused with sodium carbonate and treated by the Berzelius method as modified by Hillebrand. The slight precipitate of calcium fluoride obtained gave a distinct etching reaction on treatment with sulphuric acid. A blank experiment with approximately the same amount of reagents (oxide of lead, sodium carbonate, oxide of zinc, &c.) gave no trace of fluorine.

The result of the analysis is as follows:—

			Molecular ratios.
SiO_2	30·53		0·519
ZrO_2	19·70		0·161
Nb_2O_5	1·68[1]	1·89	0·007
Ta_2O_5	0·21[1]		
FeO	1·91		0·026
MnO	1·56		0·022
CaO	35·80		0·639
MgO	0·57		0·014
K_2O	0·43		0·005
Na_2O	6·13		0·099
F	1·28		0·068
	99·80		
less O for F_2	0·54		
	99·26		

The result agrees more closely with a formula

$$3CaSiO_3.[Ca(F,OH)]NaZrO_3$$

than with the formula $4Ca(Si,Zr)O_3.Na_2ZrO_2F_2$ suggested by Brögger for hiortdahlite. It would be rash, however, to press the claims of the above formula very strongly considering the small amount of material used in the analysis on which it is based. The weight of material used in Cleve's analysis of hiortdahlite is not stated, but was probably much greater.

[1] The individual numbers for Nb_2O_5 and Ta_2O_5 are the result of the Marignac separation, and can have little significance considering the small amount of material dealt with.

The electrostatic separation of minerals.

By T. Crook, F.G.S.

[Read March 23, 1909.]

WHEN a mineral fragment is brought under the influence of an electrostatic charge, its behaviour depends chiefly upon the conductivity of the mineral and that of the surface on which it is lying. This fact can be effectively demonstrated by placing fragments of amber (sp. gr. about 1·1) and pyrite (sp. gr. about 5) on a metallic surface, such as that of a copper plate, and noting their behaviour when a rod of vulcanite, which has been electrified by rubbing with cat's skin, is brought near them. Under these conditions a small fragment of dry amber, weighing not more than one milligram, is not attracted to the rubbed rod, although the rod be brought almost in contact with it; whilst a large piece of pyrite weighing as much as 150 milligrams jumps visibly from the plate with the rod held at some distance from it.

If we breathe on the fragment of amber, however, it is attracted to the rubbed rod with extreme readiness. Indeed, a large piece of amber is, on account of its lower density, much more readily affected than a piece of pyrite of the same size when its surface has been transformed into a good conductor by a thin film of moisture.

Pieces of pyrite or other good conductors, weighing from 10 to 15 milligrams each, dance quite merrily on a copper plate when under the influence of a charged rod; but they are practically inert if placed on a badly conducting surface, such as that of a dry glass plate.

The behaviour of pyrite as contrasted with dry amber provides an extreme example of a condition of things which prevails widely among minerals. The experiment can be done almost equally well with fluorspar, quartz, calcite, topaz, &c., in place of dry amber; but in these cases it is usually necessary to heat the fragments slightly to drive off the surface film of moisture; whereas in the case of amber this preliminary treatment is unnecessary, as it has little or no affinity for moisture.

Another way of showing this difference between good and bad conductors is to experiment with cork- or pith-balls coated with a layer of

mineral dust. These can be made by first covering balls with gum or Canada-balsam and then rolling them in mineral dust. If such balls be suspended by means of conducting threads, it will be found that balls covered with good conductors, such as pyrite, galena, graphite, ilmenite, &c., are more readily attracted by a charged rod than those covered with bad conductors, such as calcite, quartz, muscovite, fluor-spar, topaz, &c.

If the balls be suspended by insulating threads, such as dry silk, the attraction is of course less pronounced, and it is noteworthy that if the rod be not too highly excited, the bad conductors, on touching the rod, remain in contact with it, whereas the good conductors are rapidly repelled. With a highly excited rod both are quickly repelled, but the good conductors more vigorously than the bad. After having received a charge by contact in this way, the good conductors are readily attracted by one's finger and leave it almost instantly, having rapidly and completely lost their charge by contact with the finger so that they cannot be attracted a second time by presenting the finger to them. The bad conductors, on the other hand, after receiving a charge by contact with the rod, are attracted less readily by the finger and remain in contact with it for some time; but, in spite of this, they do not lose their charge completely by one contact with the finger, so that they can usually be attracted a second time. By means of this experiment the difference in behaviour between good conductors (e. g. pyrite), moderate conductors (e. g. wolframite), and bad conductors (e. g. calcite) can be readily demonstrated.

From a consideration of the above-mentioned simple experiments, we can establish the following conclusions:—

(1) Good conductors are more susceptible to electrostatic influence than bad conductors.

(2) The resultant force of attraction exerted by a charged body on a non-charged body as a consequence of influence is largely increased by the liberation of the repelled charge, and this increase is much more pronounced for a good than a bad conductor.

(3) Differences of conductivity are more important than differences of specific gravity in determining attraction under influence; and within certain wide limits as regards size of fragments, the densest good conductors are attracted preferably to the least dense bad conductors when the grains are lying on a conducting surface.

(4) A film of moisture on the surface of a bad conductor converts it into a good conductor.

(5) To the foregoing conclusions we may add that since an electro-

static charge resides on the outer surface only, and as, proportionately to its size, a small particle has a greater surface than a larger one, it follows that fine particles should be more susceptible to attraction than coarse particles of the same substance, and one finds in practice that this is the case.

These conclusions are of practical importance as suggesting an electrostatic method whereby fragments of minerals which are relatively good conductors can be separated from those which are relatively bad conductors.

If we take a mixture of ilmenite and quartz fragments; sift them so as to avoid dust and coarse pieces; place them on a copper plate, and heat the plate slightly to drive off the moisture from the surface of the grains, the ilmenite is attracted by a piece of rubbed sealing-wax, whilst the quartz is practically unaffected. The reason for this is clear from the experiments already described. By virtue of its greater conductivity, the surface of a grain of ilmenite permits a readier development and separation of charges under influence than does the surface of a dry quartz grain. For the same reason the repelled charge can escape rapidly into the metal plate from the surface of an ilmenite grain, whereas it can only escape very slowly from the surface of dry quartz. Hence the resultant attractive force exerted by the rubbed rod of sealing-wax on the ilmenite is much greater than that on the quartz. This difference is so pronounced, and the ilmenite grains remain in contact with the sealing-wax to such an extent, that a practically perfect separation of the two minerals can be made in this way.

The importance of having the grains dry can be readily shown by breathing on them, when it will be found that the quartz is attracted as well as the ilmenite. Indeed, for moist grains it is the mineral of lower specific gravity that tends to be preferably attracted.

It may be helpful to explain here how it is that small grains of the good conductors, having been attracted to the sealing-wax, remain in contact with it. When a suitably small fragment of a good conductor comes into contact with a charged bad conductor, such as sealing-wax, it depletes the charge on the sealing-wax at the point of contact to such an extent that the force of mutual attraction due to influence generally exceeds that of repulsion due to contact. It is the relation of these two forces to one another and to the force exerted by gravity which determines whether the fragment will remain in contact with the charged badly conducting rod or be repelled from it. These factors are determined by the size, density, relative conductivity, and shape of the fragments. We have already seen that pieces of a good conductor weighing

about ten milligrams are quickly repelled by a charged vulcanite rod. Fragments of a good conductor which have passed a sieve of $\frac{1}{30}$ inch mesh, however, usually remain in contact with rubbed sealing-wax.

If instead of using rubbed sealing-wax to attract the good conductors, we use a charged metal rod, the particles are repelled, even though they may be small, since in that case the charge on the metal rod at the point of contact is renewed by rapid inflow of the general charge, so that there is no serious depletion at the point of contact.

Any mineral which is a good conductor can be separated from any other mineral which is a bad conductor in the manner described above. Minerals can be roughly classified in three groups according to conductivity, as indicated by the following examples :—

Good conductors (lustre metallic).	Moderate conductors (lustre submetallic, &c.).	Bad conductors (lustre vitreous, &c.).
Ilmenite	Wolframite	Calcite
Magnetite	Cassiterite	Quartz
Galena	Rutile	Fluor-spar
Graphite	Zinc-blende	Topaz
Pyrite	Thorianite	Felspars
Molybdenite	&c.	Monazite
&c.		&c.

As roughly classified above, the good conductors can be separated quite effectively from the bad conductors. The moderate conductors can also be separated from the bad conductors, in some cases effectively, in other cases not so well. Some minerals, e. g. zinc-blende, vary considerably in their conductivity according to their chemical and physical condition. Mineral fragments can also have the conductivity of their surfaces seriously modified by artificial treatment (oxidation, &c.), so that a mixture of grains otherwise inseparable by electrostatic methods can be made separable by artificial treatment.

In conclusion, we may refer briefly to previous work on this subject and at the same time summarize the whole matter of electrostatic separation as follows :—There are three methods whereby mineral fragments can be separated electrostatically : (1) The method of electrification by mutual friction, and the attraction to oppositely charged metal plates. Negreano showed in 1902 [1] that by using a Wimshurst electrical machine red-lead and sulphur can be separated in this way. This experiment

[1] D. Negreano, ' Procédé de séparation électrique de la partie métallique d'un minerai de sa gangue.' Compt. Rend. Acad. Sci. Paris, 1902, vol. cxxxv, p. 1103 ; Électro-chimie, Paris, 1903, vol. iii, pp. 26–27.

merely imitates the well-known pyroelectricity experiment with tourmaline. But Negreano suggested that the method might be applied to the separation of fragments of 'metallic' substances from the useless vein-stuff with which they are usually associated. In another note in 1903[1] Negreano recorded results of experiments with quartz fragments mixed with fragments of gold and silver, showing that a separation could be made as he had previously suggested.

(2) A method introduced by Messrs. Blake and Morscher of Denver, Colorado, which consists essentially of allowing the mixed mineral fragments to fall on to the highly charged surface of a good conductor. By this means the fragments which are good conductors take a charge quickly by contact, and are instantly and strongly repelled, whilst the bad conductors are comparatively inert.[2] This method has been applied successfully on a commercial scale in ore-dressing operations. Some forms of the Blake-Morscher separator are rather complex, and aim at giving the mixed grains a charge before allowing them to fall on the highly and oppositely charged conducting plate.

(3) The method described in the present paper; i. e. the separation by simple influence and attraction, the good conductors being attracted to and retained by the charged surface of a bad conductor. This is the simplest and cheapest method of all, though, as far as the writer is aware, it has not been previously described. It is eminently suitable for use on a small scale in the laboratory, and there seems to be no reason why it should not be imitated on a commercial scale. It is scarcely to be hoped, however, that electrostatic methods can attain a degree of usefulness equal to that which has been attained by electromagnetic methods in the operations of ore-dressing; though in this connexion it should be remembered that the electrostatic method can be applied to cases in which the ordinary electromagnetic method is quite useless.

[1] D. Negreano, 'Séparation électrique des poudres métalliques de la matière inerte, et de la partie métallique d'un minerai de sa gangue.' Compt. Rend. Acad. Sci. Paris, 1903, vol. cxxxvi, pp. 964–965.

[2] L. I. Blake, 'Electrostatic concentration.' Engineering and Mining Journal, New York, 1905, vol. lxxix, p. 1036. Also U. S. Patents, Nos. 668791 and 668792, of February, 1901.

OBITUARIES.

Wilfrid Hudleston Hudleston (1828–1909).

By the death of Mr. W. H. Hudleston we have to deplore the loss of one of the past-presidents of the Society. Although taking no active part in the affairs of the Society during recent years, he acted as President during the years 1881–1883, at a time which witnessed several important changes. The financial position of the Society was far from satisfactory, and the practice of holding country meetings had been for the most part discontinued, while the amalgamation of the Mineralogical and the Crystallological Societies was under consideration. These and other matters affecting the welfare of the Society were discussed by Mr. Hudleston in his presidential address in 1883 (vol. v, pp. xxi–xxiv). The only paper published by him in the Magazine was a criticism 'On a recent hypothesis with regard to the diamond rock in South Africa' (Min. Mag., 1883, vol. v, pp. 199–210). Most of his papers were on geological and palaeontological subjects. He formed a collection of minerals, but a far more extensive collection of fossils, the latter, including many type specimens, having been bequeathed by him to the Sedgwick Museum at Cambridge.

He was the eldest son of Dr. John Simpson, of Knaresborough, and Elizabeth Ward, the heiress of the Hudlestons of Cumberland, and on coming into these estates in 1867 he changed his name from Simpson to Hudleston. On leaving Cambridge in 1850 he studied law and was called to the Bar, but being a man of leisure he travelled extensively in the pursuit of ornithology, afterwards turning his attention to chemistry and later to geology. A biographical notice with portrait and list of his publications appeared in the 'Geological Magazine' in 1904 (dec. 5, vol. i, pp. 431–438), and an obituary notice in the same journal in 1909 (vol. vi, pp. 143–144).

Albert Auguste de Lapparent (1839–1908).

Professor de Lapparent was best known to mineralogists as the author of the lucid 'Cours de Minéralogie', a fourth edition of which appeared only shortly before his death. Of other excellent textbooks and treatises

his 'Traité de Géologie' is of special importance; this first appeared in 1881, and a fifth edition, in three volumes, was published in 1906. His mineralogical papers were few in number; he wrote on crystal-structure in 1878, on the origin of igneous rocks, and on the eruptive rocks of Jersey. After passing as a student from the Polytechnic School at Paris, he joined the 'Corps des Mines' and was attached to the French Geological Survey. Since 1875 he was professor of geology and mineralogy at the Institut Catholique, and later also at the École libre des hautes études. In 1907 he succeeded Berthelot as secrétaire perpétuel of the Paris Academy of Sciences. He was president of the French Mineralogical Society in 1885 and again in 1906; and an obituary notice with portrait has appeared in the 'Bulletin' (1909, vol. xxxii, pp. 38–41). His charming personality was abundantly evident at the time of the centenary celebrations of the Geological Society of London in 1907, and during the subsequent visit to Cambridge, where he received the honorary degree of Doctor of Science.

Gustav Melczer (1869–1907).

The early death of Dr. G. Melczer removes a worker of considerable promise. He had already published sixteen papers, dealing not only with the crystallographic description of minerals from Hungarian localities, but also with the general crystallography of corundum, haematite, and some other species. While working in Munich in 1900 he described some of the material brought back from Ceylon by Dr. F. Grünling. He was an assistant in the Technical High School, and since 1902 Privatdozent in the University of Budapest. An obituary notice with portrait and list of his publications appeared in the Hungarian journal, 'Földtani Közlöny' (1908, vol. xxxviii, pp. 1–6, 103–106).

REVIEWS.

Cristallographie (*déformation des corps cristallisés; groupements; polymorphisme; isomorphisme*). Par FRED. WALLERANT. Pp. iii + 523, with 230 text-figures. (Paris: Librairie Polytechnique Ch. Béranger. 1909. Price 15*s.* net.)

The elaborate 'Traité de Cristallographie' of Professor E. Mallard, of which the first volume appeared in 1879, was to have been completed in three volumes. In the preface of the second, which was published five years later, it was stated that the final volume would be devoted to the facts which depend at once on the external form and the internal structure, namely, twinning, pseudosymmetric groupings, isomorphism, dimorphism, the genesis of crystals, &c. These were subjects which Professor Mallard himself had much studied, and the volume was expectantly awaited by crystallographers; but, unfortunately for the progress of the science, not only was the volume still unissued at the time of his early death in 1894, but it was found that the manuscript was not in a sufficiently advanced stage to admit of posthumous publication.

Since the issue of the first volume of Mallard's treatise, the researches of Sohncke, Schönflies, Fedorov and Barlow relative to the theory of crystal-structure, and the discovery of liquid crystals by Lehmann, have rendered it possible to make a decided advance in the correlation of various properties of crystals; and, in the light of these and similar researches, Professor Wallerant, himself a distinguished investigator, has written a book which admirably fills up the gap in the crystallographic treatise of his fellow countryman.

The following brief statement will suffice to make clear the scope of the volume and the mode of treatment adopted by the author.

The volume begins with an Introduction (27 pages) giving general ideas as to the structure of crystallized bodies; it includes an interesting sketch of the subject of liquid crystals.

The rest is divided into six Books. Book I (60 pages) treats of the homogeneous deformations of solid crystals; and gives an account of the

experimental researches which have been made relative to the development of twin-structure by pressure. In Book II (75 pages), crystalline groupings (simple and repeated twinning) are minutely discussed. Book III (40 pages) deals with apparent symmetry, and shows that all crystals whatsoever can be regarded as constituted of molecular groups with parallel orientation and each of them placed in a compartment of an approximately cubic network. Book IV (126 pages) describes the facts of polymorphism, and enters into the problems involved in the crystallization of mixtures of two substances; it includes an account of the theories of polymorphism. Book V (162 pages) gives an elaborate account of isomorphism; it includes a discussion of the relations of the composition of the mixed crystals to the composition of the mother-liquor from which they are deposited, also an account of the physical properties and structure of the mixed crystals. The last Book (26 pages) deals with the regular growths of crystals belonging to different species.

The numerous figures contribute much to making clear a volume treating of matters which are of great difficulty and at the same time of great interest. The book ought to be in the hands of every advanced student of crystallography.

L. F.

Text-book of Petrology, containing a summary of the modern theories of petrogenesis, a description of the rock-forming minerals, and a synopsis of the chief types of the igneous rocks and their distribution as illustrated by the British Isles. By Dr. F. H. Hatch. 5th edition. Pp. xvi + 404. (London: Swan Sonnenschein & Co. 1909. Price 7*s.* 6*d.* net.)

The fact that this well-known text-book has reached a fifth edition (two of them, however, being merely reprints of the second edition) shows that it has been of value to students of petrology. The first edition in 1891 contained 128 pages, the second (1892) 222 pages, and in the present edition the number of pages has been again almost doubled. The number of text-figures is also largely increased, being now 130. With such extensive additions it has been necessary to re-write the whole book, but the general arrangement of the second edition has been retained as far as possible. Part I (66 pages) deals with the mode of occurrence, structure, and composition of igneous rocks; Part II (84 pages) is devoted to the rock-forming minerals;

Part III (128 pages) to the classification and detailed description of the igneous rocks; and Part IV (104 pages) to the distribution of igneous rocks in the British Isles. An Appendix gives a concise table (4 pages), drawn up by R. H. Rastall and J. Romanes, for the determination of the commoner rock-forming minerals in thin section.

In the first part we now find a general and brief account of eutectics and the application of this principle to igneous magmas. The descriptive portion is largely increased by the addition of many chemical analyses of rocks, and many of the new names recently given to rock-varieties are included. Some of these names are quite trivial and can be of no permanent value, and being printed in the text in heavy type undue prominence is given to them, to the confusion and discouragement of the elementary student. The several sketch-maps illustrating the distribution of British igneous rocks are of especial interest. The main title of the book is perhaps somewhat misleading, since only the igneous rocks are dealt with.

Hints for Crystal Drawing. By Miss Margaret Reeks. With a Preface by Dr. J. W. Evans. Pp. xx + 148. (London: Longmans, Green & Co. 1908. Price 3*s.* 6*d.* net.)

The text of this book is in the main descriptive of forty-four full-page diagrams reproduced from the author's drawings of clinographic projections and orthographic plans of crystals. The representation of the axes in clinographic projection for the several systems of crystals is clearly explained, and the positions of the crystal-faces with reference to these axes are given by the Millerian indices. The directions of the edges are arrived at by the intersections of the several planes. This method of drawing crystals according to the principles of solid geometry is undoubtedly of considerable educational value to the student, and enables him to obtain a clear conception of the relation of the forms. On the other hand, it is perhaps more tedious than the newer methods of deducing the directions of edges from the stereographic or gnomonic projections of the poles.

The book is full of useful hints, many of which a serious student would no doubt find out for himself without following every step in the text. The reading of the text requires, indeed, a considerable amount of concentration, and it appears to be unnecessarily involved by the use of various contractions, whereby the same letter comes to have several different significations.

T

Gold and Silver; comprising an economic history of mining in the United States, the geographical and geological occurrence of the precious metals, with their mineralogical associations. By Dr. Walter R. Crane. Pp. xi + 727, with 9 plates. (New York: John Wiley & Sons; and London: Chapman & Hall. 1908. Price 21*s.* net.)

This volume has been compiled by Dr. W. R. Crane, instructor in mining at the School of Mines in the Columbia University, to form part of the series on the 'Economic History of the United States' to be published by the Carnegie Institution of Washington. It contains full details relating to the history of discovery and the occurrence of gold and silver in all parts of the United States. Although the work is written rather from an economic and mining standpoint, still many points of mineralogical interest are mentioned. In table II of the appendix a useful summary is given of the form of deposit, country rock, and associated minerals met with in the several mines of each State.

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